Technical Report 1234

Effects of Input Device and Latency on Performance While Training to Pilot a Simulated Micro-Unmanned Aerial Vehicle

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14. ABSTRACT *(Maximum 200 words)*:

The effects of input device and latency in training to manually pilot a simulated micro-aerial vehicle (MAV) were investigated. Our prior research suggested that performance was superior when using a game controller as opposed to a mouse during missions in which maneuvering skill and attention to sensory imagery were critical. This experiment investigated whether effects would persist when participants were tested in a novel environment and when some realistic latency was imposed between input command and MAV response. Fifty-six participants were trained to operate a MAV in one simulated environment and then tested with two new missions in a novel environment. Four between-group conditions were examined, formed by crossing two 2-level factors: input device (game controller vs mouse) and latency period (no time delay vs. 500 ms delay). The effects of input device replicated our prior research and also transferred to the novel environment, suggesting that input device rather than spatial learning was responsible for the differences in performance. No substantial effects of delay were found.

15. SUBJECT TERMS
Remote control, human-robot interaction, multimodal displays and input controls, robotic control, teleoperation

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EFFECTS OF INPUT DEVICE AND LATENCY ON PERFORMANCE WHILE TRAINING TO PILOT A SIMULATED MICRO-UNMANNED AERIAL VEHICLE

EXECUTIVE SUMMARY

Research Requirement:

The introduction and demonstrated usefulness of unmanned aerial vehicles (UAVs) has influenced the Army's decision to integrate these assets into the Future Combat System (FCS; Cambone, Krieg, Pace, & Wells, 2005). The employment of UAVs has increased since 2001, and they are currently used to support several missions, including those in Iraq and Afghanistan (Cambone et al, 2005). Micro-aerial vehicles (MAVs) are man-portable UAVs, which lack the infrastructure requirements of larger systems (e.g., need for a runway and dedicated ground crew). One prototype MAV (Crane, 2005) employs a ducted fan design, which gives it a unique advantage over fixed wing aerial vehicles—vertical take off and land, and the ability to hover. This prototype MAV is slated to evolve into the FCS's Class I UAV, and the U.S. Navy has already announced plans to deploy a current version in Iraq to aid in detection of improvised explosive devices (IEDs). Due to the growing interest in field uses of these vehicles, it is important that the MAV man/machine interfaces are designed to facilitate control and data interpretation, and that systematic training methods and training standards are developed.

Our prior research suggested that a game controller, affording maneuver control in multiple dimensions simultaneously, supported superior performance during MAV operator training in simulation, compared with a mouse, affording control of only one dimension at a time (Durlach, Neumann, & Billings, 2008). The performance measure was time to complete the mission. Moreover, subsequent to training, participants who had used the continuous device (the game controller) gave more positive usability ratings than participants who had used the discrete device (the mouse). The present experiment was designed to further investigate the mechanism underlying this difference. The game controller affords more focused attention on the sensory imagery than does the mouse, because it can be operated without diverting attention from the sensory image. The mouse, in contrast, requires alternating attention from the sensory image to on-screen controls, which must be selected to initiate commands. It might be this difference in attentional demands, rather than the continuous vs. discrete control afforded by the two devices, that accounted for the performance difference we observed. More focused attention on the sensor imagery may have allowed users of the game controller to better learn landmarks and spatial configurations in the synthetic environment, and it may have been this learning that supported better performance. We reasoned that if spatial learning were the cause of the performance difference, that difference should not be evident were the pilots tested in a novel environment. Therefore, in the current research, we trained pilots in one environment and then tested them in a novel environment. In addition, the possibility that the effect of input device might interact with system latency was investigated, because actual unmanned systems tend to involve such latencies.

Procedure:

Four between-group conditions were examined, formed by crossing two 2-level factors: input device (mouse vs. game controller) and latency period (no time delay vs. 500 ms delay). Fifty-six participants were randomly assigned to one of the four conditions. Participants completed MAV operator training in one simulated environment and were then tested in a novel environment. Participant performance was measured in both the practice/training environment and the novel environment. The primary dependent variable was completion time for each mission, although we did measure other variables such as collisions and subjective workload.

Findings:

We replicated the pattern of results found in our previous research. Training missions were completed more quickly with the game controller than the mouse. This difference was observed in both the training and the test environments. The effect of latency failed to be of much consequence. Subjective workload scores were little affected by input device or latency.

Utilization and Dissemination of Findings:

Continuous input devices for 3-dimensional navigation of remote vehicles seem to support more efficient mission performance, compared to discrete input devices. Our results tend to rule out the explanation of better spatial learning with the continuous device as the basis for this difference. It still may be the case that more focused visual attention with our continuous device than our discrete device contributed to this difference. The mouse requires the user to divide their attention between the sensory imagery and the input control display; this division of attention may put cognitive demands on the operator, which, although not detected in subjective measures of workload, may nevertheless cause less efficient mission performance.

In addition, during the course of this research, we have developed training regimes which could be applied in future training development for operators of MAVs. We have demonstrated that time to complete a mission is a sensitive performance measure, in that it decreased over the course of training and was sensitive to the effect of input device. In contrast, number of targets detected in a fixed-time simulated reconnaissance mission proved to be insensitive to input device, and may not be as useful as a measure of operator performance.

The results of this research have been accepted for presentation as a paper at the 2008 meeting of the Human Factors and Ergonomics Society. The results have been shared with the Human-Robot Interaction Army Technology Objective team, led by the Army Research Laboratory Human Research and Engineering Directorate. They have also been sent to PM Unmanned Aerial Systems, PM Common Controller, the Soldier Battle Lab, and the United States Army Intelligence Center, Director of Combat Development.

EFFECTS OF INPUT DEVICE AND LATENCY ON PERFORMANCE WHILE TRAINING TO PILOT A SIMULATED MICRO-UNMANNED AERIAL VEHICLE

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EFFECTS OF INPUT DEVICE AND LATENCY ON PERFORMANCE WHILE TRAINING TO PILOT A SIMULATED MICRO-UNMANNED AERIAL VEHICLE

Introduction

Unmanned aerial vehicles (UAVs) are being created to serve a variety of purposes. They have many potential applications including search and rescue operations and environmental monitoring (Sanna & Pralio, 2005). The military currently uses UAVs for reconnaissance and surveillance operations. Cutting edge technology in sensors, global positioning system (GPS) receivers, and microelectronics have led to the prospect of very small, lightweight, man portable micro-unmanned aerial vehicles (MAVs) that are deployable almost anywhere (Lyon, 2004). These systems could provide unprecedented situational awareness at small unit levels; however, the successful deployment of such systems at the lowest military echelons will require optimization of human-system interaction and efficient training procedures. Both system operators and unit leaders will require training. The operators will require training on systems operation and maintenance, and the leaders will require training on system employment (Durlach, 2007). The military has recognized the magnitude and scope of benefits that remotely operated systems can provide; but, their focus has been developing the technology, rather than optimizing human-machine interfaces or designing training procedures and standards.

Background

The design of UAV technology and controls become more advanced as technology is developed, and it is important to incorporate human factors into the design process so that UAVs can be used both safely and effectively. It has been shown that more accidents resulting in aircraft damage or the complete loss of aircraft have occurred per flight hour for UAVs than for inhabited air vehicles, and over half of these accidents have been attributed to human factors issues (Tvaryanas, Thompson, & Constable, 2005). Hence, human factors consideration should be taken into account when designing these man/machine interfaces and controls so that operators can safely and effectively pilot these unmanned vehicles. In general, there are two indispensable human roles involved in the operation of a UAV: a pilot for the vehicle, and an individual responsible for interpreting the sensor imagery (Goodrich et al, 2008). When controlling a MAV, one operator may be required to fill both of these roles simultaneously. While a substantial body of research has been devoted to the creation of the hardware needed for these systems, less research has addressed potential human-computer interface problems and the need for future training requirements. We conducted prior research that addressed the interface control display design of a simulated MAV and found several issues that should be addressed when operators must control MAVs: input device and system latency.

In a previous experiment (Durlach, Neumann, & Billings, 2008), we developed a number of operator training scenarios, and used them to conduct training of MAV manual control in a simulation environment. In manual control mode, a MAV operator can control maneuvers of the vehicle in near-real time (as opposed to way-point pre-programmed navigation, which is determined prior to launch). The sensory image sent from the vehicle to the operator interface is used to guide navigation and avoid obstacles. One purpose of the experiment was to determine the parameters of performance that might serve as suitable measures of training mastery, and thus viable candidates for establishing training standards. Another purpose of the experiment was to examine how variation in operator interface design would impact performance during training. We found that time to complete missions was sensitive to the input control device, such that participants provided with continuous control (a game controller with two thumb sticks) completed missions more quickly than participants provided with discrete control (mouse used to point and click on a set of directional icons on the display screen). The primary purpose of the present experiment was to determine if the temporal performance benefit observed with the continuous control device was constrained to the training environment or whether it would also be observed if trainees were tested in a novel simulation environment.

Input Device Issues

Existing UAVs are controlled by a variety of input devices including a touch-screen and stylus interface, traditional stick-and-rudder controls, natural language and visual gesturing interfaces, and game controllers (Chen, Haas, Pillalamarri, & Jacobson, 2006). The touch-screen and stylus interface, as found on Honeywell's Class I prototype, allows the UAV operator to control the vehicle directly through the 2-dimensional screen. The more traditional cockpit-like controls, like those for the Predator UAV, have a stick-and-rudder design in order to more closely emulate the real controls used for flying manned aircraft. In addition, some UAV controls are being designed that incorporate and feature game controllers that function to maneuver the UAV as well as tilt, pan, and zoom cameras on the UAV. The Evolution XTS, the Sentry® HP, the CyberBug, and the Raven RQ-11B all have controls similar to commercially available game controllers. The choice of input device appears to be at the discretion of the system developer rather than on research. One of the purposes of this present experiment was to contribute data upon which a more rational choice could be made.

During the course of developing protocols and standards of performance for training manual control of a prototype MAV, we previously investigated the influence of input device on trainee performance, using game controllers as opposed to a 2-dimensional input device (Durlach, Neumann & Billings, 2008). In our previous research, we chose to use a mouse as the 2-dimensional input device in place of a touch-screen and stylus. Both methods use a point-and-click approach in which attention must be directed away from the camera images, but the mouse registers inputs more reliably. We felt this was especially important considering that previous research found that users generally question the reliability of touch screens (Durlach, Neumann & Bowens, 2006). Durlach et al. (2006) found that users had trouble distinguishing between failed touches and successful touches, the results of which were merely delayed. Other research has found that performance in pointing tasks was comparable for a mouse and a stylus (MacKenzie, Sellen & Buxton, 1991). Therefore, we used a mouse in lieu of a touch-screen and stylus so that input reliability would not affect our measures. We also used a mouse out of convenience, since we were simulating MAV operation from a computer workstation. While this would most likely not be used in the field, the mouse has many of the same characteristics of a touch-screen in that both are discrete in nature and utilize point-and-click methods of command input.

We found that game controllers have the advantage of offering several degrees of freedom, or the number of directions the object can be controlled simultaneously. According to our research in this area, this form of input device may offer performance benefits over discrete devices such as touch screen and similar 2-dimensional input devices (Durlach, Neumann & Billings, 2008).

Our previous research demonstrated that trainees using game controllers completed missions more quickly than trainees using a computer mouse (Durlach, Neumann & Billings, 2008). It could be that a continuous control device is more efficient than a discrete control device for controlling the maneuver of a vehicle in three dimensions. The game controller allows flight movement in several dimensions simultaneously while the 2-dimensional mouse uses point-and-click maneuvering with an on-screen control pad (allowing movement in only one dimension at a time). If this is the reason why we found superior performance using the game controller, the performance benefit of using a continuous input versus a discrete input device should not depend on the environment. Consequently, superior performance with the continuous device should be observed in both the training and novel environments.

We cannot assert, however, that the only difference between our continuous and discrete input control conditions was the "continuity" of the input device. The participants using the game controller (continuous input device) could focus their attention on the sensor display more than the participants using the mouse (discrete input device). Those using the mouse had to divert their visual attention away from the sensor imagery with every maneuver command they issued in order to ensure that they were "clicking" on the proper control button displayed on the screen. Those using the game controller, on the other hand, could maintain visual attention on the sensor imagery (once they had mastered the finger-to-device mappings). Instead of needing to visually locate the control input, they could do it by feel and therefore did not need to divert their visual attention away from the sensor imagery as often. It is possible, therefore, that participants using the game controller had greater opportunity to learn about the spatial characteristics of the environment compared with the participants using the mouse. This in turn may have allowed participants using the game controller to better anticipate obstacles in the environment, maneuver more smoothly, and complete missions more rapidly. To the extent that differential knowledge of the training environment accounted for the performance differences observed across input conditions, this performance difference should fail to be manifest in a novel environment. The previous differential in spatial learning would be of no benefit in a new environment.

Input devices should enhance training so that attention is predominately on camera imagery and other important aspects of manually piloting the MAV rather than the actual control devices, and the game controller appeared to offer this advantage. In addition, performance tended to be better overall when the control method matched the function of the input command. For example, a discrete command (such as hovering or taking a photograph) is probably best implemented as a single discrete input (such as a mouse click or pressing a button on the game controller). Conversely, a continuous command (such as movement through a 3-D space) is probably best implemented as continuous commands (e.g., the physical movement of thumbstick controls that directly translates into MAV movement; Durlach, Neumann, & Billings, 2008). The game controller offered both continuous control and discrete control.

The purpose of our current experiment was to address which factor was responsible for the differences in performance: the input device itself or spatial learning. We, therefore, examined whether the effects of input device would persist across a change in environment. If spatial learning were responsible for the differences in performance, those differences should be specific to the training environment; consequently, the differences would not appear when participants are placed in a new simulated environment. If the differences persist in the novel environment, we can eliminate differential spatial learning as the mechanism underlying the performance effects.

Latency Issues

Latency refers to delays inherent in a system. Latencies are caused primarily by transmission time requirements, broken signals, or time required for computation. Latency can reduce operator performance in general, cause errors in operator judgment, and decrease performance in manual control and tracking tasks (Ferrell, 1965); however, much of the research on the effects of latency has provided inconsistent results. Some research has shown that unmanned vehicle operators experiencing a delay of greater than 100 ms may have increased performance errors because they cannot correct their mistakes quickly and effectively; these operators will reduce the speed of the UAV in order to maintain control of the vehicle (Miall & Jackson, 2006). Other studies have shown that target acquisition and tracking performance declined significantly when introduced with latencies anywhere from approximately 200 ms to about 320 ms, while other researchers found decrements at 500 ms (MacKenzie & Ware, 1993; Lane et al, 2002). Further research demonstrated that operator performance degraded significantly only when system latencies were greater than 1.5 seconds (Lane et al, 2002; Chen, Haas, & Barnes, 2007). These various findings do not allow one to predict whether a specific latency will or will not cause significant performance issues.

In our previous research, we did not impose any degree of latency on the system (Durlach, Neumann, & Billings, 2008). The current research seeks to examine, if the superiority of the game controller as an input device still holds, when there is a latency of 500 ms imposed between input and MAV response. We chose a 500 ms latency because subject matter experts suggested 500 ms was a realistic period of latency in MAV operation. The latency of 500 ms has been shown to produce drastic performance decrements in some studies; but, minimal effects according to other research (MacKenzie & Ware, 1993; Lane et al, 2002).

Current Research

The current research is intended to replicate and validate the findings of our previous research when the realistic limitations of latency and novel environments are applied to the simulation (Durlach, Neumann & Billings, 2008). This experiment used a 2x2 between-groups design with input device type (mouse vs. game controller) and latency between operator input and MAV movement (0 ms vs. 500 ms delay) being the independent variables. Each participant was randomly assigned to one of four conditions. Participants completed several training missions in one simulated environment, and then they completed two additional missions in a novel simulated environment, using the same input device and latency period as they used in the previous missions. All the missions used in the training environment were the same as those used in our previous research. The dependent variable that we were most interested in was completion times for the timed missions. Two of the missions in this study were fixed-time reconnaissance missions; for these, the dependent variable of interest was the number of targets photographed. In addition, we collected collision data, subjective workload assessments, and perceived latency assessments for all of the missions.

Method

Participants

Twenty-eight male and twenty-eight female participants from the University of Central Florida area completed this experiment in exchange for monetary compensation or college course credit. Ten other participants (all female) failed to meet the initial training criteria, and these participants were excused from the study. All participants were at least 18 years old, and stated they had normal color vision and vision correctable to 20/20. Of the participants who completed the entire experiment, the mean age was 21.4 years old. Each participant signed an informed consent form before any testing began.

Materials

A combination of subjective measures and questionnaires were administered during this experiment, several of which were given on a laptop computer. The paper-based materials included the Hidden Patterns Test, a matching worksheet, two scaled maps of the simulated environments used in the missions, and a modified version of the Cooper-Harper Handling Qualities Rating Scheme (ETS, 1976; Cummings, Myers, & Scott, 2006).

Research has demonstrated that spatial ability, as measured by existing psychometric tests, is significantly associated with the ability to learn spatial information from a desktop virtual environment (Waller, Knapp, & Hunt, 2001). In our experiment we used the Hidden Patterns test, which measures the flexibility of closure, to address spatial ability. More specifically, this test examines selection perception, or the ability of a participant to search for and recognize a particular visual pattern among other distracting visual stimuli (Boehm-Davis, Holt & Hansberger, 1997). We used the Hidden Patterns test because in our previous research it was significantly correlated with more of the critical dependent performance measures than other spatial tests that were used (Durlach, Neumann, & Billings, 2008).

The matching worksheet presented an image of the operator control unit (OCU) display, and the participant was instructed to match different components on the OCU display to their functions in order to assess participant understanding of the system. The scaled maps of the terrain databases (Fort Polk and Fort McKenna) were given to participants so that they could mark recalled target locations detected during tactical missions. The Cooper-Harper Handling Qualities Rating Scheme, developed in 1969, was designed to subjectively assess pilot opinions regarding some aspect of a specific flying task (Best, & Schopper, 1995). The Cooper-Harper rating scale consists of 10 possible ratings, with 1 signifying excellent or highly desirable characteristics and 10 representing major deficiencies. The modified version of this rating scale (unique to this experiment) asked participants to rate their opinions regarding operating system delay and perceived aircraft handling performance and consisted of only 7 possible ratings. The scale is illustrated in Table 1.

Table 1. Modified Cooper-Harper Handling Qualities Rating Scheme, Unique to our Experiment

System	Opinion	Rating
Excellent	I had no problems with system delays; I didn't notice any delays	1
Good	I noticed some delays; but they didn't affect how I piloted the MAV.	2
Fair, some room for improvement	I noticed some delays, which affected how I piloted the MAV; but I was able to cope with them easily, and they didn't really bother me.	3
Moderate deficiencies, could be improved	The delays were somewhat annoying, and I was aware of having to compensate for them in piloting the MAV.	4
Objectionable deficiencies, should be improved	The delays were very annoying; they really affected how I controlled the MAV; but I don't think my mission performance suffered as a result.	5
Major deficiencies, must be improved	The delays were very annoying; they really affected how I controlled the MAV. I think my mission performance suffered as a result.	6
Current system unacceptable	The delays were unacceptable. Because of system delays, there were times when I was unable to maintain control of the MAV.	7

The NASA TLX was administered via a laptop computer, and subjective workload scores were automatically calculated (Hart & Staveland, 1988). A demographics survey and a usability questionnaire were also given on a laptop computer. The demographics survey consisted of 15 items that asked participants primarily about computer and video game experience and usage. The usability survey required the participants to rate 32 different items on a 10 point Likert scale, regarding participant experiences with the OCU system.

Apparatus

The experiment was conducted using two networked computers and one non-networked laptop. The OCU, the MAV simulator, and the synthetic terrain database were all run on the first computer (which the participants used to pilot the MAV). Participants sat at a desk and interacted with the OCU using either a standard two-button, one-wheel Dell optical mouse or a Logitech dual-thumbstick game controller. The One Semi-Automated Forces (ONESAF) Testbed Baseline (OTB version 2.5) was loaded on the second computer. This allowed the experimenter to introduce dismounted Soldiers and ground vehicles into the terrain database. The non-networked laptop was used to administer the NASA TLX workload questionnaire as well as a demographics survey and a usability questionnaire.

The Simulated MAV

The simulated MAV used in the experiment was based loosely on the Class I t-MAV prototype, developed by the Defense Analysis Research Project Agency's MAV Advanced Technology Demonstration (See Figure 1). The MAV incorporated a ducted fan design that allowed for vertical lift-off and landing, hovering, rotating in place, and speeds of up to 6 knots (in manual mode). In addition, the MAV was equipped with two fixed cameras: one was pointed straight down, and one was pointed in a forward direction. MAV flight included inertial properties. For example, when a hover command was issued while the MAV was in motion, it slowed gradually before coming to a complete stationary hover. In addition, forward movement of the MAV caused the MAV (and its fixed) cameras to tilt by one degree for every knot of forward speed (like the actual t-MAV prototype).

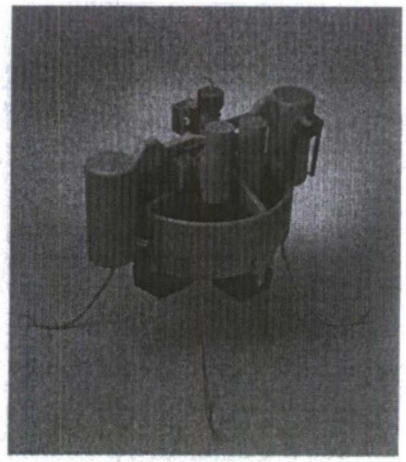

Figure1. The 2005 t-MAV prototype by Honeywell.

Operator Control Unit (OCU)

The OCU (see Figure 2) showed information necessary for mission completion (See Appendix B for mapping of commands to the OCU interface). The OCU display consisted of video sensor imagery (two camera views, but only one camera could be viewed at a time), an overhead map view of the terrain database (satellite view), a discrete control pad used for issuing flight commands (See Figure3), an altimeter, a heading tape, and several task bar icons used for issuing additional MAV commands (e.g., take-off, switching camera views, etc.). The current position of the MAV was always displayed on the map view. The mission timer was located in the upper right of the screen. Timing for each of the exercises was initiated by the operator, beginning with the issue of the take-off command and ending when the MAV was grounded. After the operator gave the "take-off" command, the MAV rose to an altitude of 60 feet above the ground, and any maneuver commands given during this time had no effect. After the "take-off" altitude was achieved, a red stop icon on the control unit illuminated; only after this could participants give maneuver commands.

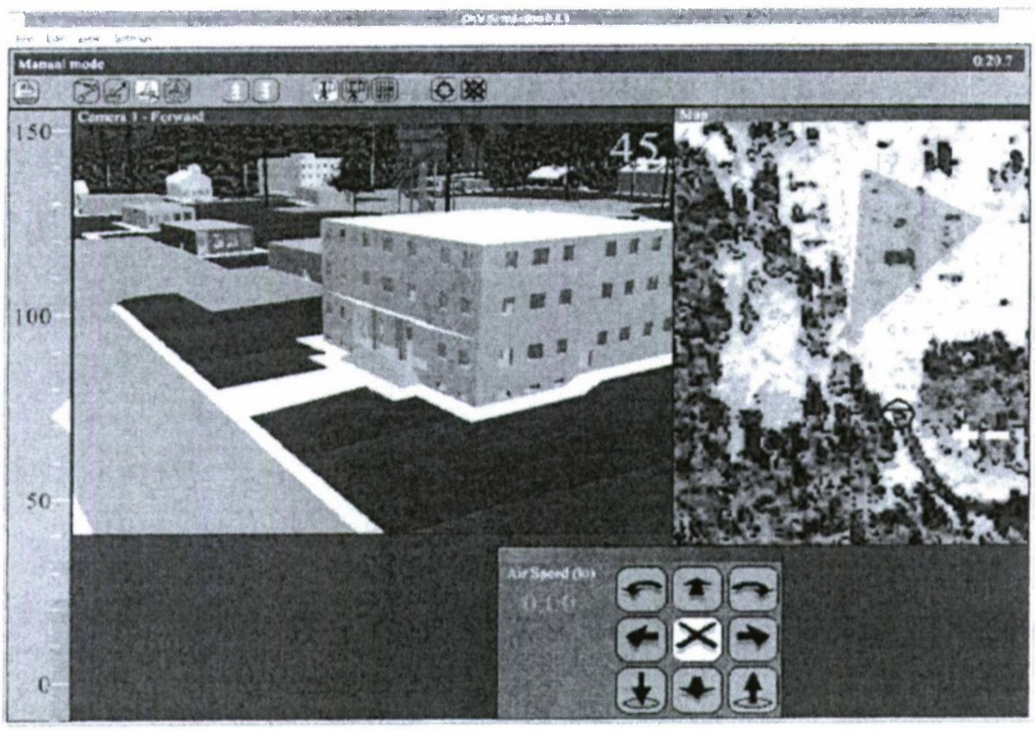

Figure 2. The OCU.

Figure 3. Illustration of the discrete input control display.

Input Devices

Participants used one of two input devices during the experiment: a mouse or a game controller. The mouse was a 2-button/1-wheel Dell optical mouse with a USB connector that was placed on a mouse pad. The game controller was a Logitech dual-thumbstick controller with a USB connector (See Figure 4). Both devices enabled the participant to issue the same commands to the MAV, only in different ways. Participants using the mouse simply had to click on the desired function on the screen to activate the OCU (See control pad in Figure 3). Conversely, participants using the game controller were required to issue commands to the OCU via the buttons on the game controller itself. The same visual feedback was given on the on-screen control pad (i.e., the command key lit up), regardless of what type of input device was used.

Figure 4. Illustration of the game controller with functions labeled. Left-right/lateral movements (left thumbstick) did not change vehicle heading.

Synthetic Environments

During the first part of the experiment, participants trained to pilot the MAV in a simulated environment based on an area of Fort Polk, LA. They were subsequently required to perform two missions in a novel synthetic environment based on an area at Fort Benning, GA. Figures 5 and 6 show overhead views of each of these environments. Besides have different

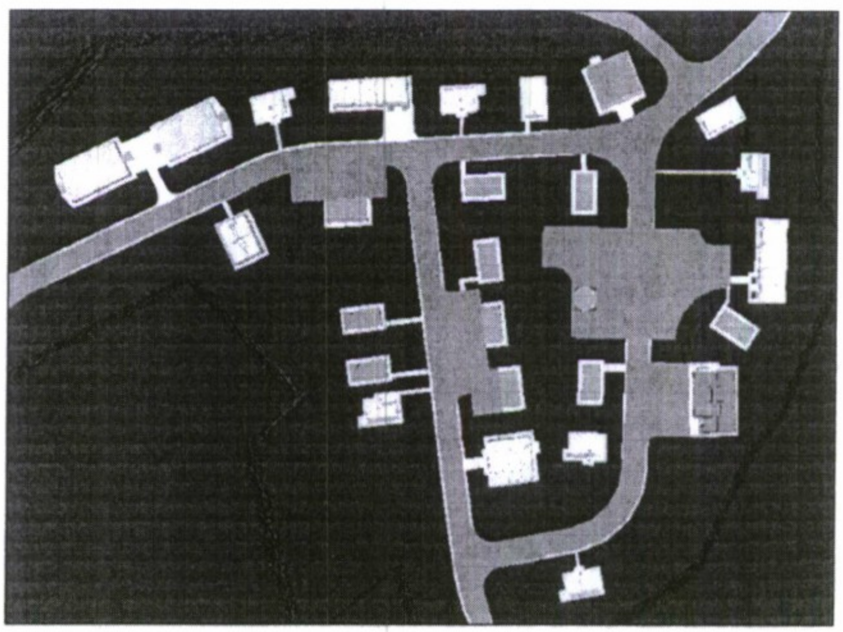

Figure 5. Overhead map view of the simulated Fort Polk training environment.

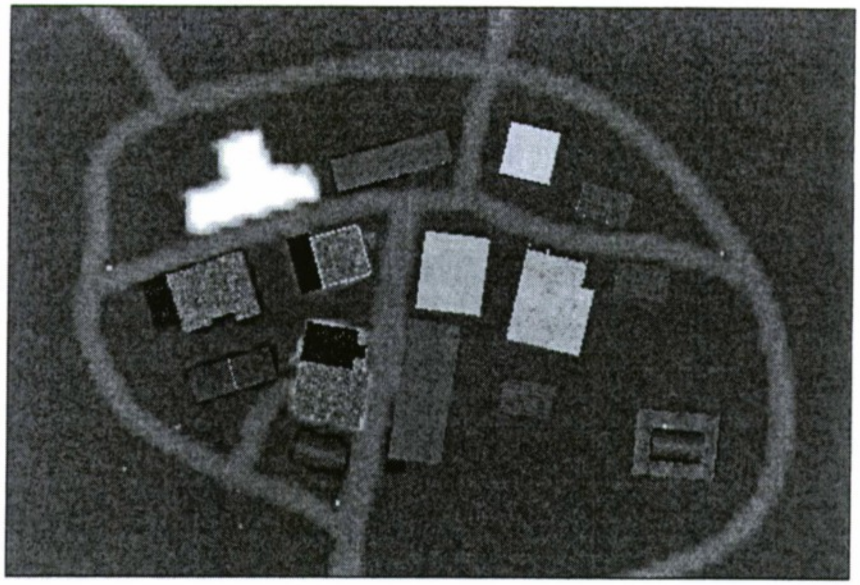

Figure 6. Overhead map view of the simulated Fort Benning transfer environment.

road and building configurations, the two areas differed in the placements of trees, powerlines, and other obstacles (which are not obvious in the figures).

Procedure

At the start, participants signed a voluntary informed consent form. Then they were instructed to complete a demographics survey, and participants were subsequently given the Hidden Patterns test to measure spatial ability. Following these preliminaries, participants were assigned to one of four conditions, determined by a 2 x 2 between-groups design where the factors were input device (mouse or game controller) and latency (no delay or 500 ms delay). There were an equal number of male and female participants in each condition. Each participant was then trained to fly a simulated MAV, equipped with a printed operator manual as well as experimenter assistance. After participants were trained on MAV capabilities and control functions, they were then required to successfully complete six practice exercises within an allotted time, all of which in the Fort Polk environment.

The first four practice exercises focused on allowing participants to learn the mapping of all buttons and their respective commands. For example, one practice exercise required participants to take several pictures from the airborne MAV, and another practice exercise required participants to perform maneuvers with the MAV as commands were given orally by the experimenter. The last two practice exercises incorporated several pre-determined mission parameters and required movement over greater distances for successful MAV operation. See Table 2 for descriptions of all practice exercises. Also see Figures 7-8 for the routes that participants were instructed to follow in the exercises. Participants who were unable to meet the criterion times on these practice exercises after 5 attempts were dismissed from the experiment. Participants who successfully completed the practice exercises within the criterion times continued on with the experiment.

Table 2. Practice/Training Exercise Instructions. All Exercises take Place in the Simulated Environment of Fort Polk

Exercise	**Instructions**
Practice Exercise 1 (read)	Execute the Take-off command. When the Red Stop icon illuminates (showing that take-off altitude has been reached), execute the Land command. This must be completed in 30 seconds (:30) or less.
Practice Exercise 2 (read)	Execute the Take-off command. At or before the completion of take-off, activate the view window for camera 2 (downward view). Take a snapshot with camera 2. Activate the view window for camera 1 (forward view). Take a snapshot with camera 1. Execute the Land command. This must be completed in 40 seconds (:40) or less.
Practice Exercise 3 (read)	The upper altitude alarm will be set at 150 feet and activated. Execute the Take-off command. Ascend to 150 feet and trigger the alarm (you'll hear a warning sound). Immediately descend to 50 feet or below without hitting the ground. Ascend back up to 100 feet but less than 150 feet. Rotate the MAV 360-degrees without dropping below 100 feet. It is required that the heading tape shows the number "0" after completing 1 rotation with the MAV. The "0" must remain in the forward camera view window before landing. Execute the Land command. This exercise must be completed in 1 minute 35 seconds (1:35) or less.
Practice Exercise 4A (auditory commands) Practice Exercise 4B (auditory commands)	For this exercise, you will follow a series of oral commands issued by the experimenter. After take-off and as soon as the Red Stop icon illuminates, you will immediately begin to hear a series of flight commands. Commands will be given as fast as you can correctly comply. Once the correct feedback is observed from the OCU, the experimenter will proceed to the next command. Practice 4A: The first series of commands after take-off should be: *Ascend, descend, fly forward, (strafe) right, (strafe) left, fly backwards, rotate right, rotate left, land.* This exercise must be completed in 1 minute 5 seconds (1:05) or less. Practice 4B: The second series of commands after take-off should be: *fly forward, rotate left, fly backwards, rotate right, (strafe) right, (strafe) left, activate camera 2, take snapshot with camera 2, ascend, descend, activate camera 1, take snapshot with camera 1, fly forward, land.* This exercise must be completed in 1 minute 25 seconds (1:25) or less.
Practice Exercise 5 (racetrack)	The experimenter will load and run this mission autonomously and will point out the Landing Zone (LZ) on the (H) building. After the autonomous mission finishes, the simulation will be reset. You must now manually pilot the MAV around the gray pathway while remaining to the left of the four red poles and then land in the correct LZ. If you do not follow directions or if you crash, you will be required to restart this exercise from the beginning. This exercise must be completed in 3 minutes 50 seconds (3:50) or less.

After the practice exercises, participants were required to complete five missions, and experimenter interaction with participants during this portion of the study was extremely limited. The first three missions were performed in the Fort Polk environment (See Table 3). Missions 1 and 2 were similar to the last two practice exercises, but had to be completed unaided by the display of waypoints on the situation awareness map. Mission 1 involved piloting the MAV around a track that was marked by poles in the synthetic environment. Mission 2 involved navigating the MAV through a slalom course. For these missions, participants who committed a collision were immediately stopped and required to restart the mission.

Table 3. Instructions for Missions 1, 2 & 3, Which occurred in Fort Polk Environment; these are Identical to Missions 1 through 3 in our Previous Research

Fort Polk Mission	**Instructions**
Mission 1	This mission is a repeat of practice exercise #5, where you piloted the MAV around the gray pathway while remaining to the left of the four red poles. The difference in this mission is that there will be no waypoints on the satellite view map. You need to try to complete this mission as quickly as possible but ***also*** without any collisions –if you have a collision or if you deviate from the course, you will be required to redo the mission from the beginning until you complete it without a collision. You will manually pilot the MAV around the gray pathway while remaining to the left of the four red poles, and then land on the (H) building. When ready, press OK to start the timer. Execute the **Take-off** command. Complete one lap around the four red poles and stay over the gray path. Land on the (H) building.
Mission 2	This mission repeats practice exercise #6, where you navigated a series of red and green poles. You will also take two snapshots of the C2 vehicle at the end of the run. The difference in this mission is that there will be no waypoints on the satellite view map. Complete the mission by flying through the series of red and green poles, and then return to your start point to take the snapshots of the C2 vehicle. You need to try to complete this mission as quickly as possible but ***also*** without any collisions –if you have a collision or if you deviate from the course, you will be required to redo the mission from the beginning until you complete it without a collision. You must complete the obstacle course manually. After you finish navigating around the poles (**right** of the green poles and **left** of the red poles), you will need to take snapshots of the C2 vehicle with both cameras. When ready, press OK and then execute Take-off. Complete the obstacle course. Take snapshot of the C2 vehicle with camera 1. Take snapshot of the C2 vehicle with camera 2. Land, but do NOT land on the C2 vehicle.
Mission 3	This mission involves using the MAV to do reconnaissance work. You will get a handout titled "Mission 3 Intel & Recon." Review this with the experimenter, and then complete the required tasks. This is primarily a target identification mission. The experimenter may ask you for situational updates during this mission. Review the "Mission 3 Intel & Recon" handout. The experimenter will load the mission files and scenario. You will have a limited time to identify as many targets as possible on the map. Positive ID can only be achieved by taking snapshots of each entity with both the forward and downward cameras, and each entity must be centered in the frame so that the center ( ) overlay is touching part of the entity. When ready press OK to begin the mission and start the timer. Immediately begin looking for entities to identify via the cameras. The experimenter will tell you when time has expired.

Mission 3 was more tactical in that participants were given an Intel sheet depicting pictures of various targets, and they were told to photograph as many entities as possible with both the forward camera and the downward camera. Fourteen targets (Soldiers and vehicles) were situated in the synthetic terrain for this mission. Participants were allowed free flight in the environment; but after 7 minutes were instructed to return to the launch site and land. They were subsequently asked to mark where they detected targets on a paper map.

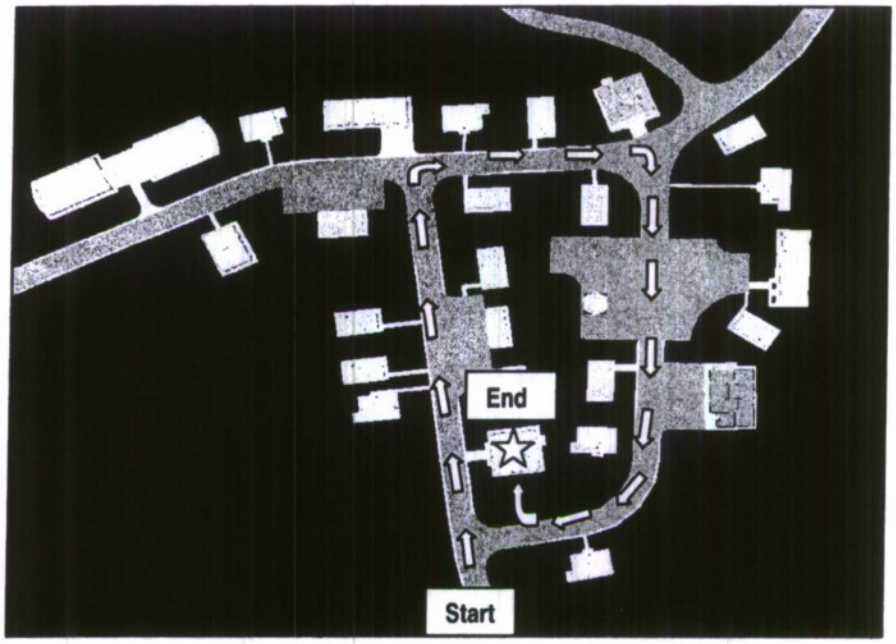

Figure 7. Mission 1: Fort Polk/practice environment racetrack route.

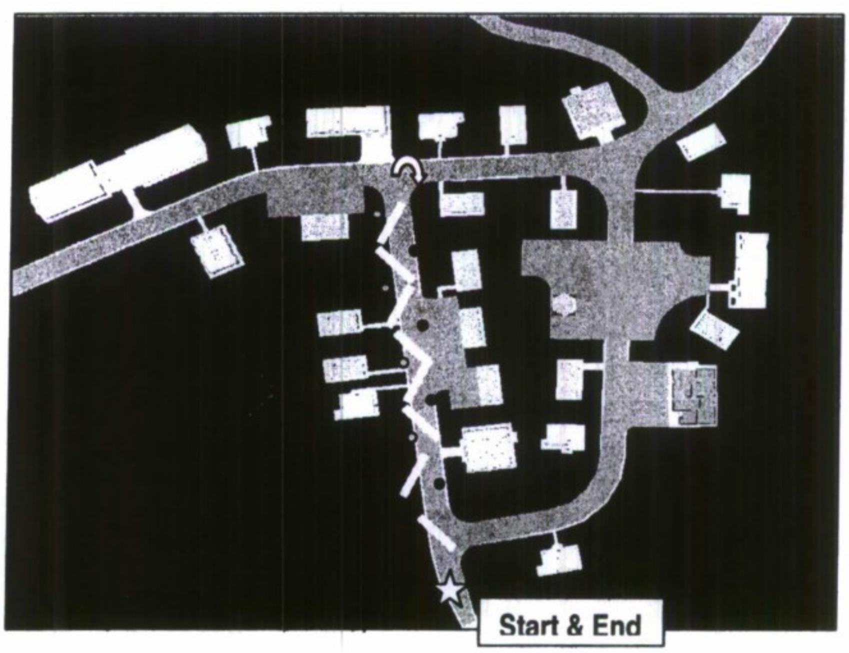

Figure 8. Mission 2: Fort Polk/practice environment slalom route.

The final two missions (outlined in Table 4) were completed in the new synthetic environment (Fort Benning). Mission 4 involved piloting the MAV through a designated course (similar to Missions 1 and 2). See Figure 9 for a map of the route that was taken in Mission 4. Mission 5 was similar to Mission 3 in that participants were given an Intel sheet with various targets and asked to fly through the simulated environment and photograph the targets. In this case, however, all the targets were dismounted Soldiers, with some located on roof tops or windows, and participants were instructed to photograph the face of each individual. After 7 minutes, participants were instructed to return to the launch point and land.

Table 4. Instructions for Missions 4 and 5, Which took Place in an Area of Fort Benning

Fort Benning Mission	**Instructions**
Mission 4	This mission involves using the MAV to navigate around obstacles. Complete the mission by piloting the MAV around the roadway, flying through the series of red and green poles, and then landing in the designated area. **You must fly to the left of the red poles and to the right of the green poles. Also, be sure to stay close to the pathway!** You need to try to complete this mission as quickly as possible but ***also*** without any collisions or deviations from the course –if you have a collision, you will be required to redo the mission from the beginning until you complete it without a collision. The experimenter will load and run this mission autonomously with waypoints visible. Observe how the MAV passes to the **right** of all green poles and to the **left** of all red poles. You must now complete the course manually. You must navigate the obstacle course without crashing before you can move on to the final mission. When ready, press OK and then execute **Take-off.** Complete the obstacle course. Land in the designated area. This exercise must be completed without crashing in as many tries as necessary. There is no time limit.
Mission 5	This mission involves using the MAV to do more reconnaissance work. You will get a handout titled “Mission 5 Intel & Recon.” Review this with the experimenter, and then complete the required tasks. This is primarily a target identification mission. The experimenter may ask you for situational updates during this mission. Review the “Mission 5 Intel & Recon” handout. The experimenter will load the mission files and scenario. You will have a limited time to identify as many targets as possible on the map. Positive ID can only be achieved by taking snapshots of each entity with the forward camera so that the person’s face is visible and identifiable. When ready press OK to begin the mission and start the timer. Immediately begin looking for entities to identify via the cameras. The experimenter will tell you when time has expired.

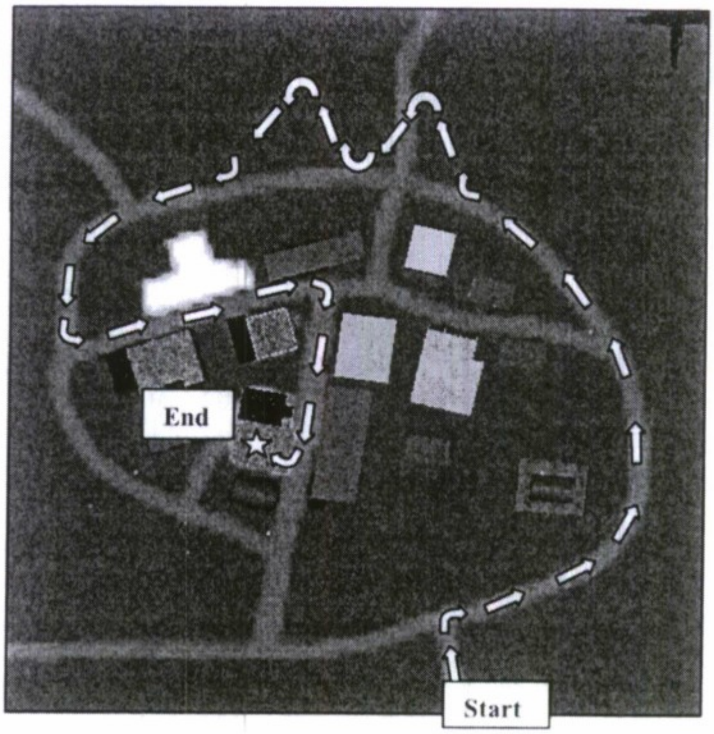

Figure 9. Mission 4: Fort Benning/novel environment transfer skills mission route.

After each mission, participants completed a modified Cooper-Harper Latency Rating Scale along with the NASA TLX. In addition, after Missions 3 and 5, participants were given a scaled map view of the terrain database and asked to mark the locations of the targets that they identified. After Mission 5, participants were given a usability questionnaire, which asked questions in regard to the system and its piloting capabilities. Finally, participants were given a debriefing form and compensated for their time.

Results & Discussion

Data Analysis

Before any analyses were performed, data was screened for any issues that could potentially affect the results. Outliers beyond ± 2 standard deviations (SD) were transformed to 1 unit (based on each dependent measure) outside the most extreme positive or negative score falling within 2 *SD* of the mean (Tabachnick & Fidell, 1996). Scores on the Hidden Patterns spatial test were converted to standardized scores for the analyses. In addition, the responses to the three demographics questions related to video game experience and skills were combined into a single index, video game experience (VGE). VGE was correlated significantly with gender (Spearman $r = .36$), with higher VGE associated with male participants. The four conditions were checked for equivalence on VGE and spatial ability; no significant differences across conditions were detected.

We intended to use analysis of covariance (ANCOVA) with spatial ability scores (standardized Hidden Pattern scores) and VGE as covariates. Before any data was analyzed, data were checked to make sure ANCOVA assumptions were met for normality and parallelism of covariates; if not, then non-parametric tests were conducted (Mann-Whitney U).

Practice Exercises

Table 5 shows the distribution of the number of attempts required for successful completion of each practice exercise. Both spatial ability and VGE tended to correlate negatively with number of attempts required to complete the practice exercises. The only significant correlation, however, was between spatial ability and number of attempts required to complete the third practice exercise (Spearman $r = -.36$). For the racetrack practice exercise, the number of attempts violated the ANCOVA assumption of normality. The Mann-Whitney U test indicated that the number of attempts was significantly affected by input device, U = 261.5, $p = .03$. The mean number attempts for the mouse was 2.5 (*SD* = 1.4), and the mean number of attempts for the game controller was 1.8 (*SD* = 1.1). For the slalom practice exercise, no significant effects of input device or delay on number of attempts were found.

Table 5. Number of Participants Requiring 1 to 5 Attempts to Complete each Practice Exercise

Attempts: Practice Exercise	Criterion Time (Minutes: Seconds)	1	2	3	4	5
1 (written)	0:30	55	1	0	0	0
2 (written)	0:40	56	0	0	0	0
3 (written)	1:35	31	22	2	1	0
4a(oral)	1:05	55	1	0	0	0
4b (oral)	1:25	56	0	0	0	0
Racetrack	3:50	26	9	11	7	3
Slalom	5:00	25	18	7	3	3

Note. For exercises 1, 2, and 3, participants read a list of maneuvers themselves. For exercises 4a and 4b, participants responded to a list of maneuvers read aloud by the experimenter. The final two practice exercises involved negotiating courses. N = 56.

A 2 x 2 (input device x latency) between subjects ANCOVA was performed on workload scores following participant completion of the practice exercises. Spatial ability was found to be a significant covariate of subjective workload scores, $F(1,50) = 4.93$, $p = .03$, $\eta_p^2 = .09$. VGE was also found to be a significant covariate, $F(1,50) = 7.16$, $p = .01$, $\eta_p^2 = .13$. Both higher spatial ability and higher VGE were associated with lower subjective workload (Spearman *r's* = -.25 and -.37 for spatial ability and VGE respectively) . The subjective workload scores for the practice exercises were also significantly affected by input device, $F(1, 50) = 5.12$, $p = .03$, $\eta_p^2 = .09$. Workload scores were significantly higher for participants using the mouse (mean 59.8; *SD* = 18.5) than for participants using the game controller (mean 48.1; *SD* = 20.7). This difference was not apparent in the baseline TLX measure, $F(1,50) = 0.47$,$p = .50$. Mean baseline TLX scores were 29.3 (*SD* = 17) and 30.9 (*SD* = 18.5) for the mouse and game controller conditions, respectively.

The ANCOVA was performed on latency ratings given following completion of the practice excises. Ratings failed to be significantly related to VGE or spatial ability, but were significantly affected by input device, $F(1, 50) = 4.91, p = .03$. Mean latency ratings were 3.0 ($SD = 1.3$) and 2.3 ($SD = 1.2$) for the mouse and the game controller, respectively. These ratings failed to be directly affected by latency itself ($F < 1$). There was a hint of an input device by latency interaction, however, $F(1, 50) = 3.12, p = .08, \eta_p^2 = .06$. Mean latency ratings for the delay and non-delay conditions were 2.1 ($SD = 1.0$) and 2.5 ($SD = 1.3$) respectively, if participants used the game controller; but were 3.4 ($SD = 1.6$) and 2.6 ($SD = 0.9$) respectively, if participants used the mouse.

Mission 1

Mission 1 was similar to Practice Exercise 5, except there were no waypoints on the satellite map and no time limit. Although participants were instructed to avoid collisions, 4 participants had a collision on their first attempt. All but one succeeded on their second attempt, and that person succeeded on their third attempt. The ANCOVA was performed on collision-free completion times. These were significantly affected by input device, $F(1, 50) = 7.49, p = .01.$, $\eta_p^2 = .13$. Participants using the game controller completed the mission significantly faster (mean 203.3 s; $SD = 16.2$) than participants using the mouse (mean 213.8 s; $SD = 11.9$). Latency failed to have a significant effect on completion time, $F(1,50) = 1.11, p = .30$. Mean completion time for the no-latency condition was 206.6 s ($SD = 15.5$), and the mean completion time for the latency condition was 210.5 s ($SD = 14.7$).

The mean subjective workload for Mission 1 (across conditions) was 38.4 ($SD = 19.8$). The ANCOVA was performed on workload scores. VGE was found to be a significant covariate of workload $F(1,50) = 13.22, p = .00, \eta_p^2 = .21$. Higher VGE was associated with lower reported workload scores. Input device and latency each failed to have a significant effect on workload scores.

Latency ratings were skewed to the left and therefore analyzed non-parametrically. Latency ratings were significantly affected by latency condition, $U = 268.5, p = .035$. Mean latency rating for the delayed group was 2.7 ($SD = 1.3$), whereas mean latency rating for the non-delayed group was 2.0 ($SD = 1.0$).

Mission 2

Mission 2 was a repeat of practice exercise 6, except there were no waypoints on the satellite map and no time limit. Although participants were instructed to avoid collisions, 15 participants had a collision on their first attempt. Participants with collisions were very evenly spread among the four conditions (3 from the mouse-delay condition, and 4 each in the remaining three conditions). For the 15 people who restarted the mission, 10 were successful on their second attempt. Four were successful on the third attempt, and the final person succeeded on their fourth attempt.

The completion times for collision-free Mission 2 violated the ANCOVA assumption of homogeneity of slopes. The results of a Mann-Whitney U test indicated that participants using the game controller completed these missions faster (mean 238.3s; $SD = 30.8$) than participants using the mouse (254.3 s; $SD = 21.6$), $U = 236$, $p = .01$. There failed to be any significant effect of latency, $U = 384.5$, $p = .90$. Mean completion time for the no-latency condition was 245.8 s ($SD = 30.1$), and the mean for the latency condition was 246.8 s ($SD = 25.4$).

The mean subjective workload for Mission 2 (across conditions) was 43.8 ($SD = 20.8$). The ANCOVA was performed on workload scores. VGE was found to be a significant covariate of subjective workload for Mission 2, $F(1,50) = 4.54$, $p = .04$, $\eta_p^2 = .08$. Higher VGE was associated with lower scores. In addition, spatial ability was found to be a significant covariate of workload, $F(1,50) = 6.09$, $p = .02$, $\eta_p^2 = .11$. Higher spatial ability scores were associated with lower workload scores. Input device and latency failed to have significant effects on workload scores. Mean latency rating across conditions for Mission 2 was 2.3 ($SD = 1.2$), and failed to be affected significantly by input device or latency.

Mission 3

All participants were given seven minutes to complete as much of the mission as possible. The performance dependent variable was the number of targets photographed. In scoring performance, one point was awarded for each entity that was photographed with both cameras (½ point for each camera view). The maximum possible score for targets photographed was 14. The number of targets photographed was significantly correlated with VGE (Spearman $r = .27$). The ANCOVA was performed on the number of targets photographed. Input device had a marginally significant effect on targets photographed, $F(1,50) = 3.08$, $p = .09$, $\eta_p^2 = .06$, with participants using the game controller photographing more targets (mean 7.0; $SD = 2.4$) than participants using the mouse (mean 6.0; $SD = 2.2$). Latency had no significant effect on targets photographed, $F(1,50) = 2.36$, $p = .13$. The means were 6.0 ($SD = 2.2$) and 6.9 ($SD = 2.4$) for the latency and no-latency conditions, respectively.

After landing, participants were asked to recall the type and location of targets observed during the mission. To do this, they marked target locations on a scale map of the terrain. One point was awarded for each target the participant correctly identified within a 2" diameter circle. Two points were assigned for each target correctly identified within a 1.25" diameter circle. A point was awarded for each vehicle correctly identified. On this map, all of the targets faced north. Another point overall was awarded for identifying this orientation. The maximum possible score for this task was 43. The mean score on this map test was 22.6 ($SD = 6.8$) in the game controller condition and 18.5 ($SD = 6.8$) in the mouse condition. The post-test scores for Mission 3 violated the ANCOVA assumption of homogeneity of slopes; according to a Mann-Whitney U test this difference was significant for input device, $U = 263$, $p = .03$; but a test for the effect of latency failed to indicate any impact, $U = 325.5$, $p = .28$.

If participants collided with an object during this mission, they were not restarted; instead, the number of total collisions was recorded. Twenty-eight of the 56 participants collided at least once during the mission, and the mean number of collisions was 2.5 ($SD = 3.8$). The total number of collisions was significantly correlated with the number of targets photographed (Spearman $r = -.27$) and spatial ability (Spearman $r = -.29$), although there were no significant effects of input device or delay. Higher spatial ability yielded fewer collisions, and fewer collisions were associated with a greater number of identified targets.

The mean subjective workload across conditions for this reconnaissance mission was 60.3 (SD = 19.8). The ANCOVA was performed on workload scores. While spatial ability was not a significant covariate, VGE was a significant covariate of workload $F(1,50) = 4.12$, p =.05, $\eta_p^2 = .08$. Higher VGE was associated with lower workload scores. Neither input device not latency produced significant effects on workload.

The mean latency rating across conditions for this reconnaissance mission was 3.3 (SD = 1.7). The latency scores for Mission 3 violated the ANCOVA assumption of normality, and nonparametric tests failed to indicate an effect of input device or latency.

Summary of replicated missions.

The results of input device in this experiment were almost identical to those obtained in our previous research. Table 6 shows that impacts of input device were the same for each mission, except for Mission 3. In the current experiment, an advantage for the game controller not seen in the previous experiment was detected. In the present experiment, participants were able to better recall Mission 3 targets and place them accurately on a paper map if they had conducted the mission with the game controller as opposed to the mouse. This latter result seems relevant to the issue of whether better spatial learning might underlie the advantages of using the game controller, because better spatial learning should facilitate performance in these recall task. The results for Mission 4 and 5, in a novel environment, address this question.

Table 6. Comparison of Significant Effects of Input Device (+) for Identical Missions in Current and Previous Research

		Previous Experiment	Current Experiment
Practice	Workload	(not reported)	+
Mission 1	Completion time	+	+
	Collisions	0	0
	Workload	0	0
Mission 2	Completion time	+	+
	Collisions	0	0
	Workload	0	0
Misison 3	Photo-score	0	0
	Map-score	0	+
	Collisions	0	0
	Workload	0	0

Mission 4 (Transfer of Flight Skills to a Novel Environment)

During Mission 4, only four participants had a collision, and out of these, only one participant collided more than once. The ANCOVA performed on completion times indicated that these times were significantly affected by input device, $F(1, 50) = 14.51$, $p = .00$, $\eta_p^2 = .23$. Completion took longer in the mouse condition (mean 259.5 s; SD = 19.8) than in the game controller condition (mean 232.9 s; $SD = 30.0$). Latency had a marginally significant effect on completion times, $F(1,50) = 2.97, p = .09, \eta_p^2 = .06$; participants without latency completed the mission faster (mean 240.4 s; $SD = 26.4$) than participants with latency (mean 252.0 s; $SD = 29.9$).

The mean subjective workload for Mission 4 (across conditions) was 43.2 ($SD = 20.9$). The mean latency rating score was 2.4 ($SD = 1.2$). Both measures violated the ANCOVA assumption of homogeneity of slopes, and results of nonparametric tests failed to indicate any significant effects.

The data collected from this transfer skills mission demonstrate that the temporal advantage of the game controller over the mouse is not specific to the training environment. Mission completion time differences were still evident even when participants were placed in a novel environment. These results suggest that differences in spatial learning cannot account for the performance differences.

Mission 5 (Transfer Tactical Mission Performance to a Novel Environment)

Our previous research failed to find a difference in number of targets photographed or recalled across the different input device conditions, when mission duration was fixed. Nevertheless, we decided to include a similar tactical mission in the transfer environment in this experiment. It is possible that demands of negotiating a relatively new environment might reveal some differences due to input device that were not detectable in the more familiar environment. Mission 5 was a tactical exercise much like Mission 3. Twelve entities (all Soldiers) were imported into the terrain database, and participants were given seven minutes (although they did not know the duration) to identify as many of these entities as possible. Participants were required to take a photograph of each entity's face with the forward camera in order to achieve positive identification. In scoring performance, one point was awarded for each entity that was photographed. The maximum possible score for targets photographed was 12. The resulting data violated ANCOVA assumptions, and nonparametric tests failed to reveal any significant effects of input device or latency. Mean targets photographed was 7.9 ($SD = 1.9$). This measure was significantly correlated with VGE (Spearman $r = .28$).

After landing, participants were asked to recall the location of targets observed during the mission. To do this, they marked target locations on a scale map of the terrain. One point was awarded for each target the participant correctly identified within a 2" diameter circle. Two points were assigned for each target correctly identified within a 1.25" diameter circle. If a participant correctly identified an entity's vertical location (ground, 2nd floor, or tower), he received an additional point. Further, one point was assigned for each entity that was correctly marked as either armed or unarmed. The maximum possible score for this task was 48. The mean number of targets correctly recalled on the map was 18.3 ($SD = 12.3$). The scores on this test violated the ANCOVA assumption of normality. Nonparametric tests failed to reveal any significant effects of input device or latency.

Sixteen of the 56 participants had one or more collisions during Mission 5. There failed to be any relation between collisions and condition. The mean subjective workload for Mission 5 (across conditions) was 51.4 (*SD* = 18.9). The workload ratings violated the ANCOVA assumption of homogeneity of slopes, and nonparametric testing failed reveal any significant effects.

Latency ratings were higher in the delay condition (mean 2.9; *SD* = 1.6) than the no-delay condition (mean 2.1; *SD* = 1.1), and this difference was significant according to the ANCOVA, $F(1, 50) = 4.57, p = .04, \eta_p^2 = .08$. There failed to be an effect of input device on latency rating.

The data collected from Mission 5 show no significant effects of input device on performance; however, such results were expected based on our previous research. One possible interpretation is that input device is not that influential when free flight is permitted, and the pilot does not have to follow a prescribed course. Another possibility is that our measures in the tactical missions (i.e., number of targets photographed and/or recalled in a fixed time) are relatively insensitive, compared to the temporal measures used in the flight skill missions.

Usability Questionnaire

The Usability Questionnaire was administered after the final mission. Participants were asked to rate various aspects of the MAV simulation, using a Likert scale, where 1 was the most favorable rating and 10 was the least favorable rating. Averaged over all usability questions, the mean usability score was 3.0 (*SD* = 0.8). A repeated measures ANCOVA on Usability Questions revealed an interaction of question and input device, $F(31, 1550) = 9.93, p = .00, \eta_p^2 = .17$, and also, question and VGE, $F(31, 1550) = 1.51, p = .04, \eta_p^2 = .03$. Therefore, we performed separate analyses of individual questions. Table 7 lists the questions for which the participants in the game controller condition rated the item significantly more favorably (lower score) than participants in the mouse condition, whereas Table 8 lists the questions with opposite results.

Table 7. Mean Usability Scores for Questions for which Participants using the Game Controller gave Significantly more Favorable Ratings (lower scores) than Participants Using the Mouse

Usability Question	Mean Mouse	*SD* Mouse	Mean GC*	*SD* GC*	$F(1,50)$	η_p^2
6) The system I worked with was... 1 flexible---------- rigid 10	4.4	2.2	3.2	1.7	5.77, $p = .02$	.10
21) The system provided adequate feedback when I issued a command to the MAV. 1 always---------- never 10	3.4	2.1	2.1	1.3	8.50, $p = .01$	.15
29) The responsiveness of the system to my input was... 1 fast enough-too slow 10	4.6	2.7	3.1	1.5	7.35, $p = .01$	.13

*GS = game controller

Table 8. Mean Usability Scores for Questions for which Participants Using the Mouse Gave Significantly more Favorable Ratings (Lower Scores) than Participants Using the Game Controller, along with Corresponding Statistics

Usability Question	Mean Mouse	*SD* Mouse	Mean GC*	*SD* GC*	*F*(1,50)	η_p^2
7) The functions of the on-screen manual control buttons (on the control pad) were... 1 clear-------- confusing 10	1.4	0.9	2.2	1.9	4.92, $p = .03$	.09
12) As I progressed through the missions using the [joystick/mouse], my hands and/or wrists became fatigued. 1 never---------- always 10	1.7	1.3	8.4	2.1	191.40, $p = .00$	.79

*GC = game controller

In our previous research (2008), we found that nine questions were rated more favorably from the game controller condition, including questions pertaining to ratings of the system itself, feedback, MAV control, and awareness of exercise objectives. In the current research, participants in the game controller condition rated three questions more favorably than participants in the mouse condition. The findings for only one question were identical over both studies, and this question related to feedback that was given after a command had been issued. Previous research also showed that the mouse condition rated one question (which was related to system speed) significantly more favorably than the game controller condition. This was not found in our current research. Instead we found that a question relating to physical fatigue was rate significantly more favorably by the mouse condition. This is surprising because workload scores throughout the experiment did not reflect this difference between input devices.

VGE was found to be a significant covariate of one item. When asked to rate how clear or confusing the display was, participants with higher VGE gave more favorable ratings, $F(1,50) = 4.94, p = .03, \eta_p^2 = .09$, Pearson $r = .30$. This was not found in our previous research (Durlach, Neumann, & Billings, 2008). In addition, there was an overall lack of effect of latency for each question.

Failures

Out of 66 participants who began the experiment 10 females failed to meet practice exercise criteria. Examining demographic and spatial ability data, the only significant difference between this group and those who completed the experiment was their self-reported video game skill. For the question "How would you rate your video game skills—(1) novice/beginner, (2) intermediate, or (3) expert?", the group who completed the experiment rated themselves with significantly higher video game skills (mean 1.7; $SD = 0.7$) than the group who did not meet the practice criteria (mean 1.2; $SD = 0.4$), U = 165, $p = .04$.

Conclusions

In our experiment, we intended to replicate and extend our previous research, which suggested that operator performance was quicker and more efficient when using a game controller rather than a mouse (Durlach, Neumann, & Billings, 2008). Faster mission completion is an important concern for MAV operators because smaller UAVs have restricted air time due to limited battery and/or fuel capacity. The findings of the present research replicated the findings of our previous research. Performance advantages of the game controller over the mouse were manifest in quicker completion times in both the training environment and the novel environment. The fact that the performance benefits of the game controller carried over to the novel environment suggests that the difference due to input device cannot be attributed to differential spatial learning.

We previously interpreted the benefits to of the game controller to the ability it affords to continuously control maneuver in multiple dimensions. Conversely the mouse affords discrete control in one direction at a time. There are other differences between the game controller and the mouse that could contribute to the performance difference, however. One important difference is the division of visual attention. The mouse requires the operator to constantly reorient visual attention, between the sensor image and the interface control display (arrows). In contrast, for the game controller, once its functions are mastered, the operator can focus attention entirely on the sensor imagery. As there are no visual icons that must be "clicked on," there is no need to attend to the interface control display (although it did provide feedback). It is this difference in attention to the sensor image which we hypothesized might account for a difference in spatial learning. Although the present data suggest that a difference in spatial learning did not account for the performance difference, it still may be that the opportunity to focus visual attention more completely on the sensor image accounted for the benefits of the game controller. Such focused attention should lower cognitive demands and opportunities for change blindness (Durlach, 2004; Rubinstein, Meyer, & Evans, 2001; Wickens & Liu, 1988). Perhaps a better-designed input control display (e.g., integrated display with visual overlay) would reduce operator performance differences. However, even with a change in the display, the game controller allows more focused attention because there is little reason to deviate from the sensory imagery. With a visual overlay, a person using the mouse would still need to refocus to some extent on the control he/she is clicking.

In our current research, the benefits of the game controller were primarily restricted to the flight skill missions. One exception was that for Mission 3, those using the game controller were able to more accurately report target characteristics and locations post-mission. It is possible that the flight skill missions, with their heavy emphasis on speed, maneuver, and obstacle avoidance may have unique sensitivity to reveal performance differences due to input device. On the other hand, it is possible that the difference in sensitivity lies not in the mission requirements, but in the dependent variables used to measure performance. The temporal measures were taken on an interval scale without restricted range. The measures used to count targets detected and collisions were taken on an ordinal scale. The collisions measure, in particular was poorly suited to statistical analysis, consisting of mostly 0's and 1's. Perhaps tactical missions that are conducted to completion (all targets detected) and timed would reveal performance benefits of the game controller over the mouse as well.

With regard to latency effects, no significant effects of delay on performance were found. Neither did latency seem to affect subjective workload. Significant subjective reports of latency were found, for Missions 1 and 5. The 500 ms latency condition reported noticing latency to a greater extent than the no-latency condition. It seems therefore, that the 500 ms latency did not have much of a detectable detrimental effect, and of most relevance for the present research, did not undermine the performance benefits of the game controller over the mouse.

Research should consolidate and address all of the necessary control mechanisms for MAV operation. Many control mechanisms for vehicle operation do not function in isolation of other control devices. For instance, in our research we did not look at keyboard usage in conjunction with MAV operation, yet realistically this may be a mode of communication between commander and MAV operator in the field. As such, it would be advantageous to design a system that incorporates all control mechanisms on the same operator control unit so that switching between mechanisms is minimized.

Future research should also continue to address the impact of input device as well as the different levels of system latency on performance in the operation of unmanned systems. As the military increases its use of these systems, human-system interaction will be become an increasingly important area of concern. Our experiments were conducted in a lab with the participant sitting at a desk. We did not manipulate any environmental conditions such as weather, which can affect system performance. Therefore, the results we have presented favoring continuous over discrete input devices must be tested for resiliency in more realistic usage environments.

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Appendix A

Acronyms

ANCOVA	Analysis of Covariance
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
DARPA	Defense Advanced Research Projects Agency
FCS	Future Combat Systems
ICD	Input Control Display
IED	Improvised Explosive Devices
GPS	Global Positioning System
MAV	Micro-Aerial Vehicle
NAV	Nano-Aerial Vehicle
OCU	Operator Control Unit
ONESAF	One Semi-Automated Forces
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SD	Standard Deviations
TLX	Task Load Index
UAS	Unmanned Aviation Systems
UAV	Unmanned Aerial Vehicles
VGE	Video Game Experience

Appendix B

Illustration of Operator Control Unit Display Configuration

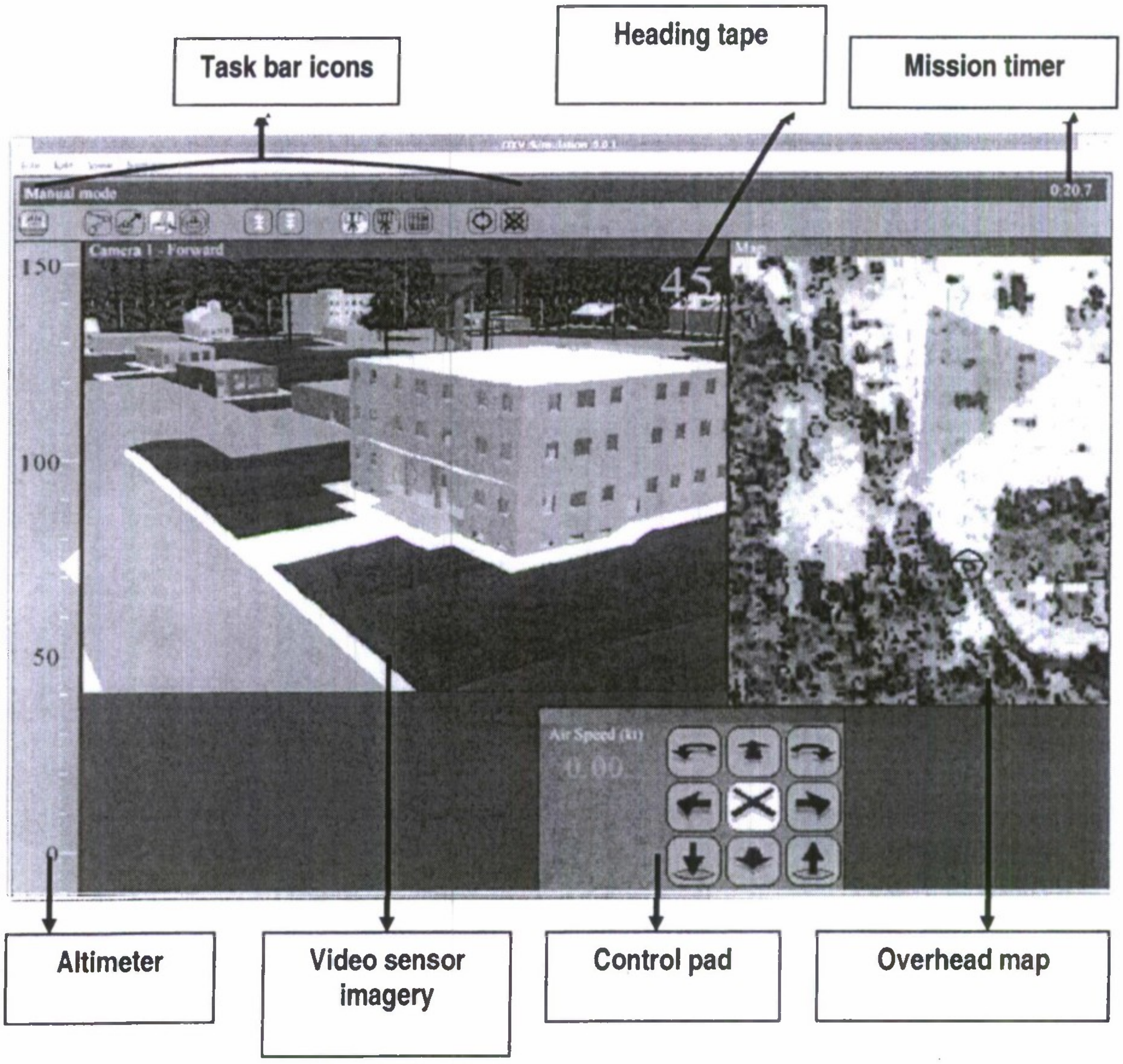


Figure B-1. OCU, single view camera layout with discrete input control.

Appendix C

Participant Training Guide

A training manual was produced for the game controller, and a different training manual was created for the mouse. To create these, an original "baseline" guide was edited to take into account the required variations for each condition.

The following gives the training manual for participants in the game controller conditions.

Army Research Institute
Intuitive Means of Robotic Control
Testbed

Participant's Guide

GC/Joystick

INSTITUTE for SIMULATION & TRAINING

MAV Study – IST 1

Spring/Summer 2007

Introduction to the Micro-Unmanned Aerial Vehicle Study

The U.S. Army is undergoing a major transformation. One element of the transformation is the introduction of a new class of military platforms known as unmanned air and ground vehicles (*called UAVs and UGVs*). A major benefit of these unmanned vehicles is that they can perform reconnaissance missions and survey areas contaminated with radiological, chemical, or biological agents without risk to human life. They can also survey the battlefield and provide real-time video feedback.

We are investigating the design of operator control systems for micro-unmanned aerial vehicles that can perform these kinds of reconnaissance missions. In addition, we are investigating operator training requirements. In this experiment, you will be trained on how to fly a simulated micro-UAV (MAV), and then you will complete a set of missions that will test your ability to maneuver the MAV and locate various targets. After each mission, you will be given a short questionnaire that asks you to rate certain aspects of the task you performed.

We have allotted approximately 3 hours for this experiment. No previous flight experience is necessary to participate in this study.

Confidentiality

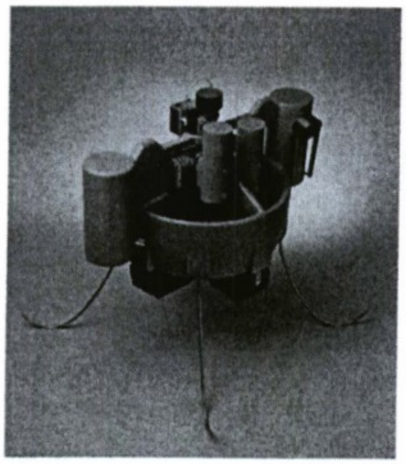
Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in an electronic file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

If you are prepared to participate in this experiment, please read and sign the **Consent Form and Voluntary Agreement**. Please also indicate on that form your preferred method of compensation. We offer cash payment or course credit. Also, please feel free to ask the experimenter any questions. Keep in mind that you do have the right to withdraw from this experiment at any time, for whatever reason.

When you have finished reading and signing the voluntary consent form, please return it to the experimenter.

<u>Overall Description of the MAV Simulation</u>

You will be working with a simulation for flying a micro-unmanned aerial vehicle. The micro-UAV itself will be referred to from now on as "the MAV." This is not a fixed-wing aircraft like most airplanes are; rather, it is a small rotary craft with an internal fan and duct design (see prototype photos below). An operator controls the MAV using a laptop computer equipped with an input device such as a mouse or joystick controller. <u>This interface is referred to as the OCU – Operator Control Unit</u>. This is a dismounted control unit, as it is envisioned that a dismounted Soldier (on foot rather than in a vehicle) will be controlling the MAV.



MAV prototypes from Honeywell and Allied Aerospace .

<u>Introduction to the OCU and MAV Camera System</u>

The MAV is equipped with a dual camera system. When the vehicle flies through the simulated environment you will be able to view video images sent back to the OCU. You will be instructed on how to operate the cameras as well as how to use the OCU interface and controllers to pilot the MAV. You will also have an opportunity to practice some manual flight/piloting techniques before beginning the actual experiment. After basic instruction, a training session will take place; then you will move on to the assigned pilot mission tasks where performance data will be recorded. Be sure that you understand the objective of each mission <u>before</u> starting a trial. The experimenter is available to answer your questions before you begin each task, so please ask for help if you are unsure of any requirements. Unless instructed otherwise, **it is important that you complete each task as quickly and efficiently as possible.**

At the end of the training session and at the end of each mission you will complete a short computer-based questionnaire. In the first section you will rate different aspects of the task you performed; then you will be asked to choose between a pair of items that

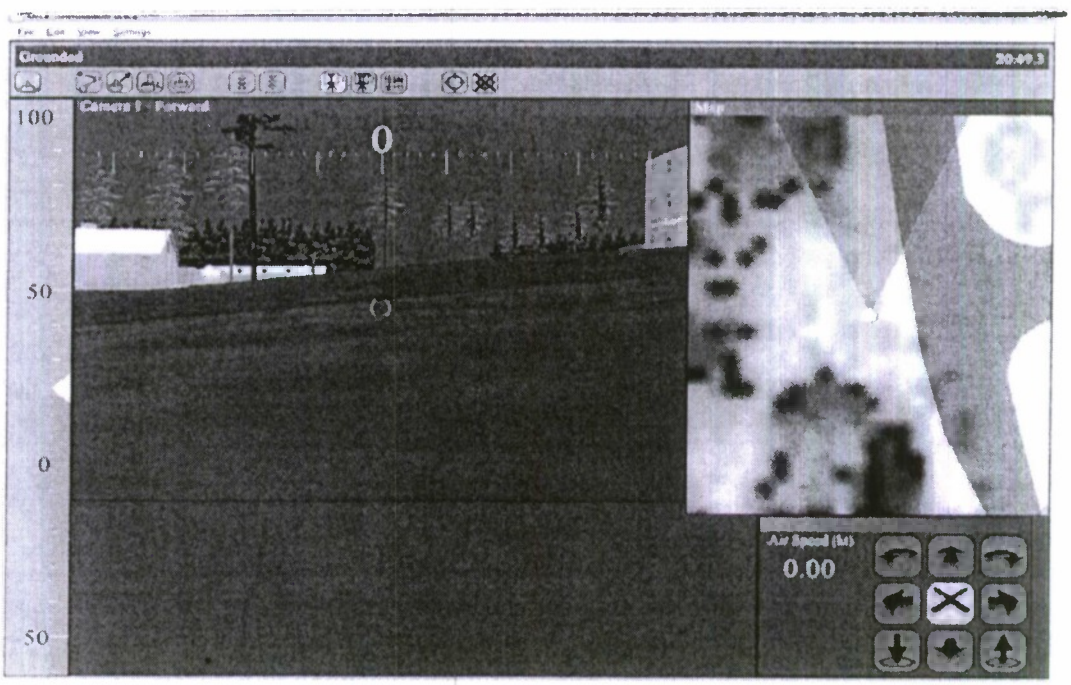
relate to your performance. You must choose one and only one item for each pair. Then you will proceed to the next mission.
Please let the experimenter know when you are finished reading these sections.

Training Session

The goal of training is to familiarize you with the flight characteristics of the MAV and to give you an opportunity to practice piloting the MAV in manual mode. We will begin by reviewing the features of the OCU and then proceed to a series of practice exercises. The experimenter will facilitate this training session and provide instruction on how to complete the assigned tasks.

OCU Layout and On-Screen Controls

Below you will see a sample layout of the OCU. On the left side of the screen is the video sensor imagery (camera views), and in the upper-right side you will find an overhead map view of the terrain database—this is the satellite view of the MAV. Just below the map view there is a control pad that is used for issuing flight commands to the MAV. The control pad will be examined in greater detail throughout training. There is an altimeter along the left border area of the OCU display as well as a task bar along the top that contains various icons. You will be instructed on how to use all relevant gauges and icons during training.



OCU with single view overlapping cameras with discrete input control pad

The experimenter will handle tasks such as loading mission files and scenarios, so you only need to focus on learning how to operate the MAV itself. Before beginning the flight training exercises, we will learn about the function of the OCU in more detail.

Understanding the Task Bar Icons

The **upper task bar** (shown below) includes the **take-off (and landing), mission mode, and camera control buttons.** There is also a mission timer located on the far right of this task bar. For this study, you will need to know how to use the take-off icon and the camera control icons.

Take-off & Landing icon

You can **take off and land** by pressing button (10) on the joystick controller to activate the task bar icon for take-off and landing. ALSO, button (10) acts as the "OK" button to begin the missions.

Once the take-off button is pressed, the MAV will automatically climb to an altitude of approximately **60 feet above the ground level**. You will see a red stop sign icon illuminate when you have reached take-off altitude. Pressing the take-off button again will execute the land command. You may land the MAV now.

Activating Camera Views and Taking Snapshot Photos

These camera buttons allow the operator to switch between the two available camera images. This study uses a two camera setup. On the OCU, camera image #1 is the view from the MAV's forward camera, and camera image #2 displays the view from the downward camera. In this experiment, one camera view will be displayed at a time so there will be a need for the operator to switch views to **activate** a camera for taking snapshots.

One of the unique features of the OCU is the ability to take snapshots with either camera. Before taking a snapshot, you will need to activate the camera that you want to take the picture. The active camera image will always have a ( ) overlay in the center of the image. The corresponding icon on the task bar will also illuminate. To change the active camera view, you must use the joystick to activate the group of icons on the task bar and select the camera you want.

To activate a camera view: This is done by pressing and holding joystick button (**2**) while you scroll through the available camera views with the directional pad. The experimenter will demonstrate this feature now.

If not already airborne, try taking off and switching the camera view. Snapshots of targets can now be taken using button (**9**) on the game controller/joystick.

Main Window Components

Altimeter - (See vertical bar on the left side of this page)

The ruler-like markings on the altimeter displays the altitude of the MAV in feet above sea level. Red tabs may be visible on the upper and lower regions of the display if the experimenter has chosen to activate the altitude alarm system. The red areas simply mark the altitudes that will activate the alarm if the MAV passes into this "red zone."

< The white triangle cut-out (left) points to the current altitude of the MAV. In this case, the MAV is approximately 82 feet above sea level.

The light brown column at the lower end of the bar marks the altitude of the nearest surface below the MAV (this is the current ground level).

Note!~ In the current example, the MAV is approximately 82 feet above sea level, but the ground level is approximately 22 feet. This means the MAV is only 60 feet above ground!

Discrete Manual Input Control Pad

This control pad lets you control the position of the MAV manually. For this display, nine buttons are used as the interface to the MAV. The four arrow icons move the MAV forwards, backwards, (strafe) left, and (strafe) right. The curved arrow icons in the upper corners rotate the MAV left and right. The lower corner icons move the MAV up and down. The middle X icon stops the MAV. Your airspeed is also shown here in knots, and the max speed is 6 knots. You will issue these commands to the MAV by using the joystick/game controller. Joystick training is next.

Note on Input Controller Feedback

Because you are using the joystick to control the MAV, the control display will activate when an input is received. The display provides feedback in this way to the operator that a command has been issued and is being executed. Arrow icons on the discrete control pad will illuminate when that command has been entered (e.g., when you push forward on the joystick, the forward arrow will illuminate). The brighter the icon gets, the faster you are traveling.

Joystick / Game Controller

The joystick/game controller is shown below, and by now you have at least performed some basic tasks with this device. We will now go over how to use the joystick for all of the tasks required during this experiment.

Controlling MAV movement with the Joystick:

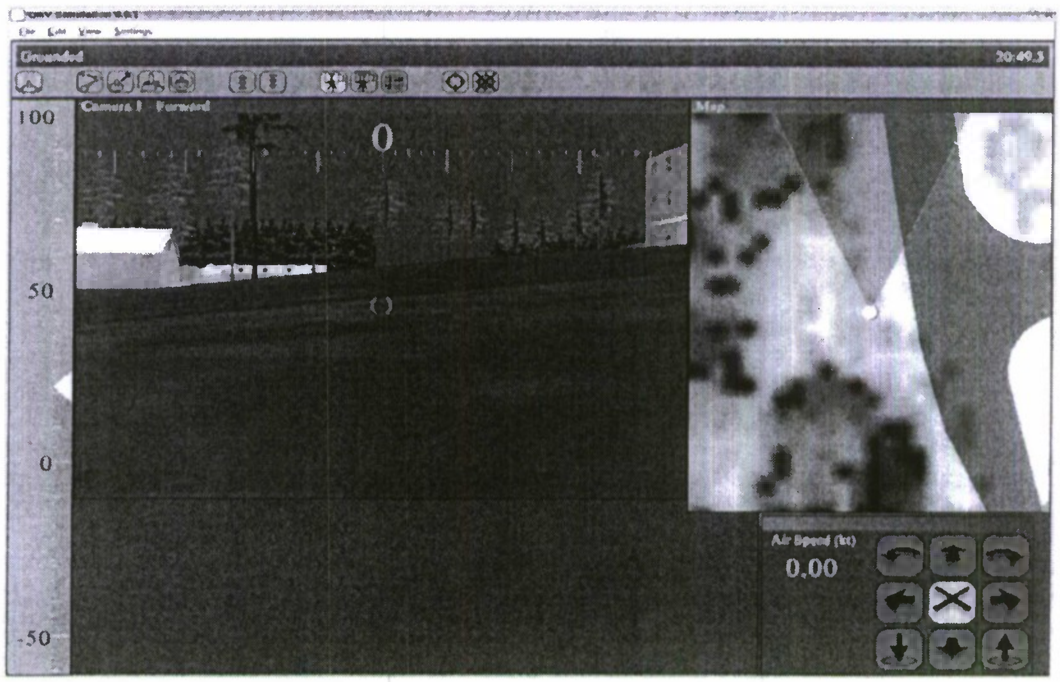
The **left thumb stick** controls movement forward, backward, and sideways (or at angles), but the MAV heading never changes when the left thumb stick is used. Pushing up on this thumb stick moves the MAV forward. Pulling down on the stick moves the MAV backwards. Moving the stick from side to side moves the MAV right or left without altering heading.

The **right thumb stick** controls altitude and heading/rotation. Pushing up on the stick increases the MAV's altitude, and pulling down decreases altitude. Moving the right thumb stick from side to side rotates the MAV in place.

It is possible (and expected) to use both sticks simultaneously to rotate, change altitude, and move at the same time. At this time, you may take off and practice manipulating the thumb sticks for approximately 1-2 minutes.

Heading Tape

Note that the camera view window has a **heading tape** located along the top edge of the frame. This number indicates the current heading of the vehicle (based on 360 degrees) with regard to that camera image. Because the cameras have been locked in place for this experiment, you can assume that the forward camera view heading is the same as the MAV heading. So if the heading tape reads "270" then you know the MAV is facing due West.



0-degrees is the same as due North on a regular compass. 90-degrees = East; 180-degrees = South; 270-degrees = W.

Important Note!! ~ The downward camera view is locked at 90 degrees from horizontal (this is essentially straight down). However, when the MAV is in motion the vehicle tilts in a similar manner to a moving helicopter. This tilting will cause the downward camera to point slightly backwards, thus giving the operator a heading reading that is opposite of the forward camera view. **i.e. if the forward camera heading is 0-degrees, then the downward camera heading will read 180-degrees <u>only while the MAV is in motion.</u>**

Practice Time: Now that you have learned all the functions of the OCU and the flight controls, we will complete a series of practice exercises beginning on the next page.

Practice Exercises

These exercises will give you a chance to practice the various tasks required to complete the missions in this study.

Warm Up

Start this warm up session by executing a take-off and briefly practicing the following maneuvers. You will notice that inertia comes into play when trying to stop the MAV, so you will need to learn to estimate things like stopping distances and rotational velocity carry-over. You want to avoid collisions at all costs! We will go over the warm up exercises one by one. As I read the maneuvers, please try to move the MAV accordingly with the joystick:

1) Move the right thumb stick up and down to make the MAV ascend and descend.
2) Move the right thumb stick side to side to rotate the MAV.
3) Move the left thumb stick up and down to make the MAV fly forward and backwards.
4) Move the left thumb stick side to side to move the MAV laterally. Note that the heading only changes when you rotate the MAV with the right thumb stick.
5) Activate camera 2, and then activate camera 1. Now switch back to camera 2 and take a snapshot [joystick button (9)].
6) Land the MAV.

Next you will complete a series of timed practice exercises. The experimenter will observe these exercises and determine if you have met the time requirement before allowing you to proceed to the next exercise. All mission and properties files needed for these exercises will be loaded by the experimenter.

Practice Exercise 1: DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) Press OK (button 10) to start the simulation and timer.
2) Execute the **Take-off** command.
3) When the Red Stop icon illuminates, execute the **Land** command.
4) This must be completed in 30 seconds (:30) or less.

<u>Practice Exercise 2:</u> DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) Press OK (button 10) to start the simulation and timer.
2) Execute the **Take-off** command.
3) At or before the completion of take-off, activate the view window for camera 2 (downward view).
4) Take a snapshot with camera 2.
5) Activate the view window for camera 1 (forward view).
6) Take a snapshot with camera 1.
7) Execute the **Land** command.
8) This must be completed in <u>40 seconds</u> (:40) or less.

<u>Practice Exercise 3:</u> DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) The upper altitude alarm will be set at 150 feet and activated.
2) Press OK (button 10) to start the simulation and timer.
3) Execute the **Take-off** command.
4) Ascend to 150 feet and trigger the alarm (you'll hear a warning sound).
5) Immediately descend to 50 feet or below without hitting the ground.
6) Ascend back up to 100 feet but less than 150 feet.
7) Rotate the MAV 360-degrees <u>without dropping below 100 feet</u>. It is required that the heading tape shows the number "0" after completing 1 rotation with the MAV. The "0" must remain in the forward camera view window before landing.
8) Execute the **Land** command.
9) This exercise must be completed in <u>1 minute 35 seconds</u> (1:35) or less.

<u>Practice Exercise 4: Rapid Command Execution:</u> DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise (both Part A and Part B), and let me know when you have finished.

For this exercise, you will follow a series of oral commands issued by the experimenter. After take-off and as soon as the Red Stop icon illuminates, you will immediately begin to hear a series of flight commands. Commands will be given as fast as you can correctly comply. Once the correct feedback is observed from the OCU, the experimenter will proceed to the next command.

Note: It is not important that the MAV travels any considerable distance. The purpose of this exercise is to allow you to learn the mapping of all buttons and icons and their corresponding functions. The experimenter is looking mainly for the correct feedback from the OCU control pad located in the lower right of the display.

Rapid command execution - Part A

1) Press OK (button 10) to start the simulation and timer.
2) Execute Take-off.
3) The first series of commands after take-off will be: **9 commands**
4) This exercise must be completed in 1 minute 5 seconds (1:05) or less.

The experimenter will now reload the properties file and reset the timer.

Rapid command execution - Part B

1) Press OK (button 10) to start the simulation and timer.
2) Execute Take-off.
3) The first series of commands after take-off will be: **14 commands**
4) This exercise must be completed in 1 minute 25 seconds (1:25) or less.

The next two exercises involve flying the MAV over longer distances and following pre-determined mission parameters. These will be similar to the missions you will complete during the remainder of the experiment.

Practice Exercise 5: DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

In this exercise you will pilot the MAV around the main roadway that forms an oval in the map. Waypoints will be visible in the overhead map view window. Waypoints are used to determine the correct flight path of the MAV. The experimenter will explain this to you in more detail while the MAV completes the mission autonomously. If you do not follow directions or if you crash, you will be required to restart this exercise from the beginning. Be careful NOT to hit the poles!

1) The experimenter will load and run this mission autonomously and will point out the Landing Zone (LZ) on the (H) building.
2) After the autonomous mission finishes, the simulation will be reset.
3) You must now manually pilot the MAV around the gray pathway while remaining to the left of the four red poles and then land in the correct LZ.
4) When ready, press OK (button 10) to start the timer.
5) Execute the **Take-off** command.
6) Complete one lap around the four red poles and stay over the gray path.
7) Land on the (H) building.
8) This exercise must be completed in 3 minutes 50 seconds (3:50) or less.

<u>Practice Exercise 6:</u> DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

In this exercise you have obstacles to navigate. You will also take two snapshots at the end of the run. Complete the mission by flying through the series of red and green poles, and then return to your start point to take the snapshots. If you do not follow directions or if you crash, you will be required to restart this exercise from the beginning. Be careful NOT to hit the poles!

1) The experimenter will load and run this mission autonomously. Observe how the MAV passes to the **right** of all green poles and to the **left** of all red poles.
2) At the end of the run you will see the command-control (C2) vehicle parked on the sidewalk. (This is you! You control the MAV from this position inside the vehicle.)
3) You must now complete the course manually with a few additional instructions: **After you finish navigating around the poles, you will need to take snapshots of the C2 vehicle with both cameras before landing the MAV.**
4) When ready, press OK (button 10) and then execute **Take-off.**
5) Complete the obstacle course.
6) Take snapshot of C2 vehicle from camera 1.
7) Take snapshot of C2 vehicle from camera 2.
8) Land – <u>but do NOT land on the C2 vehicle.</u>
9) This exercise must be completed in <u>5 minutes</u> (5:00) or less.

You will now complete a short computer-based questionnaire and a paper-based training questionnaire. The experimenter will explain this and give you instructions at this time. Then you will begin a series of 5 missions.

Mission Protocol

There will be 5 missions for you to complete during this portion of the study. The experimenter will instruct you on mission requirements and provide any documentation necessary. If you are unsure of any of these requirements, please ask for clarification. Once you begin a mission, the experimenter will have very limited interaction with you. He/she will not be able to answer questions on mission requirements once you execute the Take-off command. Please ask any questions beforehand.

Mission 1

This mission is a repeat of practice exercise #5, where you piloted the MAV around the gray pathway while remaining to the left of the four red poles. The difference in this mission is that there will be no waypoints on the satellite view map. You need to try to complete this mission as quickly as possible but ***also*** without any collisions –if you have a collision or if you deviate from the course, you will be required to redo the mission from the beginning until you complete it without a collision.

DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) You will manually pilot the MAV around the gray pathway while remaining to the left of the four red poles, and then land on the (H) building.
2) When ready, press OK to start the timer.
3) Execute the **Take-off** command.
4) Complete one lap around the four red poles and stay over the gray path.
5) Land on the (H) building.

Complete the computer-based questionnaire at this time, and then proceed to Mission 2.

Mission 2

This mission repeats practice exercise #6, where you navigated a series of red and green poles. You will also take two snapshots of the C2 vehicle at the end of the run. The difference in this mission is that there will be no waypoints on the satellite view map. Complete the mission by flying through the series of red and green poles, and then return to your start point to take the snapshots of the C2 vehicle. You need to try to complete this mission as quickly as possible but ***also*** without any collisions –if you have a collision or if you deviate from the course, you will be required to redo the mission from the beginning until you complete it without a collision.

DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) You must complete the obstacle course manually.
2) After you finish navigating around the poles (**right** of the green poles and **left** of the red poles), you will need to take snapshots of the C2 vehicle with both cameras.
3) When ready, press OK and then execute Take-off.
4) Complete the obstacle course.
5) Take snapshot of the C2 vehicle with camera 1.
6) Take snapshot of the C2 vehicle with camera 2.
7) Land, but do NOT land on the C2 vehicle.

Complete the computer-based questionnaire at this time, and then proceed to Mission 3.

Mission 3

DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

This mission involves using the MAV to do reconnaissance work. You will get a handout titled "Mission 3 Intel & Recon." Review this with the experimenter, and then complete the required tasks. This is primarily a target identification mission. The experimenter may ask you for situational updates during this mission.

1) Review the "Mission 3 Intel & Recon" handout.
2) The experimenter will load the mission files and scenario.
3) You will have a limited time to identify as many targets as possible on the map.
4) Positive ID can only be achieved by taking snapshots of each entity with both the forward and downward cameras, and each entity must be centered in the frame so that the center ( ) overlay is touching part of the entity.
5) When ready press OK to begin the mission and start the timer.
6) Immediately begin looking for entities to identify via the cameras.
7) The experimenter will tell you when time has expired.

Complete the computer-based questionnaire at this time and then proceed to Mission 4.

Mission 4

This mission involves using the MAV to navigate around obstacles. Complete the mission by piloting the MAV around the roadway, flying through the series of red and green poles, and then landing in the designated area. **You must fly to the left of the red poles and to the right of the green poles. Also, be sure to stay close to the pathway!** You need to try to complete this mission as quickly as possible but ***also*** without any collisions or deviations from the course –if you have a collision, you will be required to redo the mission from the beginning until you complete it without a collision.

DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

1) The experimenter will load and run this mission autonomously with waypoints visible. Observe how the MAV passes to the **right** of all green poles and to the **left** of all red poles.
2) You must now complete the course manually. You must navigate the obstacle course without crashing before you can move on to the final mission.
3) When ready, press OK and then execute **Take-off.**
4) Complete the obstacle course.
5) Land in the designated area.
6) This exercise must be completed without crashing in as many tries as necessary. There is no time limit.

Complete the computer-based questionnaire at this time and then proceed to Mission 5.

Mission 5

DON'T BEGIN UNTIL I TELL YOU TO DO SO! Read through the following exercise, and let me know when you have finished.

This mission involves using the MAV to do more reconnaissance work. You will get a handout titled "Mission 5 Intel & Recon." Review this with the experimenter, and then complete the required tasks. This is primarily a target identification mission. The experimenter may ask you for situational updates during this mission.

1) Review the "Mission 5 Intel & Recon" handout.
2) The experimenter will load the mission files and scenario.
3) You will have a limited time to identify as many targets as possible on the map.
4) Positive ID can only be achieved by taking snapshots of each entity with the forward camera so that the person's face is visible and identifiable.
5) When ready press OK to begin the mission and start the timer.
6) Immediately begin looking for entities to identify via the cameras.
7) The experimenter will tell you when time has expired.

Complete the computer-based questionnaire at this time along with a post-test, and then you may proceed to your final debriefing session.

Appendix D

Demographics Questionnaire

1. Participant Number	

2. Today's Date	

3. Year of Birth	

4. Gender	○	Male	○	Female

5. Have you graduated from High School?	○	Yes	○	No

6. Which hand do you write with?	○	Right	○	Left

7. Is your vision in each eye correctable to 20/20?	○	Yes	○	No

8. To your knowledge are you color blind?	○	Yes	○	No

9. Do you own or have access to a computer?	○	Yes	○	No

10. If yes, how often do you use a computer?	
Daily	○
Several times a week	○
Occasionally	○
Never	○

11. Estimate how many hours per week you use a computer.	
Never	○
1-5 hours	○
5-10 hours	○
10-20 hours	○
20-30 hours	○
30-40 hours	○
40 + hours	○

12. How would you rate your computer skills?	
Novice/Beginner	○
Intermediate	○
Expert	○

13. Do you use the Internet?	○	Yes	○	No

14. Do you have any previous remote control (R/C) experience?	○	Yes	○	No

15. Do you own or use a video game system?	○	Yes	○	No

16. How would you rate your video game skills?	
Novice/Beginner	○
Intermediate	○
Expert	○

17. How often do you play video games?	
Daily	○
Several times a week	○
Occasionally	○
Never	○

11. Estimate how many hours per week you play video games.	
Never	○
1-5 hours	○
5-10 hours	○
10-20 hours	○
20-30 hours	○
30-40 hours	○
40 + hours	○

13. Select any of the following game consoles that you either own or have used on a regular basis.		
□ Microsoft XBOX	□ Sony Playstation	□ Sony Playstation 2
□ XBOX 360	□ Sega Dreamcast	□ Nintendo Gamecube
□ Super Nintendo	□ PC game system	

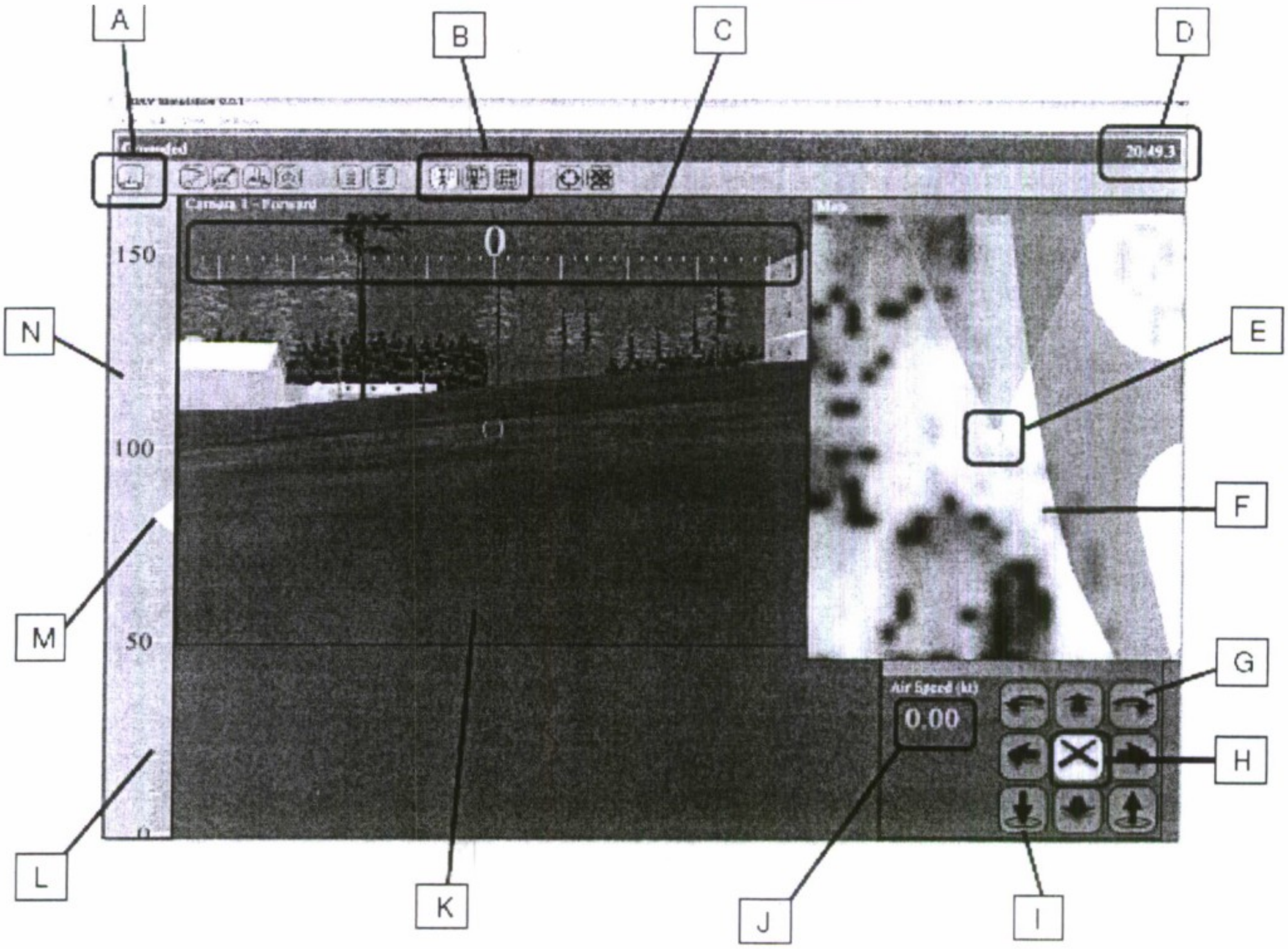
14. How would you rate your video game skills?	
Novice/Beginner	○
Intermediate	○
Expert	○

15. How many days in the past week have you played video games?	
0	○
1	○
2	○
3	○
4	○
5	○
6	○
7	○

16. Estimate how many hours per day you play video games on average.	
0	○
1	○
2	○
3	○
4	○
5	○
6	○
7	○
8	○
More than 8 hours per day	○

Appendix E

MAV Training Evaluation Worksheet



To ensure that you have a basic grasp of the MAV pilot interface and the available flight commands, please complete the following exercise.

Each of the critical features of the user interface is labeled above with letters A – N. Every letter must be used only once, so choose the best answer. Enter the corresponding letter in the blank following each of the item descriptions below:

Altimeter ______
Mission Timer ______
MAV Rotational Icons ______
Heading Tape ______
Satellite Map View ______
Current MAV Altitude ______
Forward Camera Image ______

Camera Selection Icons ______
Altitude Control ______
Take-off and Land Icon ______
Halt Movement Icon ______
MAV Location on Map ______
Ground Level Indicator ______
Air Speed Indicator ______

Appendix F

MAV USABILITY QUESTIONNAIRE (Game controller or mouse)

Circle the number that best describes your reaction between the 2 extremes given.

1) The system I worked with was

wonderful									terrible
1	2	3	4	5	6	7	8	9	10

2) The system I worked with was

easy									difficult
1	2	3	4	5	6	7	8	9	10

3) I found this experience

satisfying									frustrating
1	2	3	4	5	6	7	8	9	10

4) The system I worked with seemed

Capable of doing the exercises									Unable to do the exercises
1	2	3	4	5	6	7	8	9	10

5) I found this experience

stimulating									dull
1	2	3	4	5	6	7	8	9	10

6) The system I worked with was

flexible									rigid
1	2	3	4	5	6	7	8	9	10

7) The functions of the on-screen manual control buttons (on the control pad) were

clear									confusing
1	2	3	4	5	6	7	8	9	10

8) The functionality of the buttons for switching between camera views was

clear									confusing
1	2	3	4	5	6	7	8	9	10

9) Organization of information on the video display screen was

clear									confusing
1	2	3	4	5	6	7	8	9	10

10) Current status (such as Taking off, Landing, Grounded) messages were

adequate									inadequate
1	2	3	4	5	6	7	8	9	10

11) When controlling the MAV in flight using the joystick, the device was

easy to use									difficult to use
1	2	3	4	5	6	7	8	9	10

12) As I progressed through the missions using the joystick, my hands and/or wrists became fatigued

Never									Always
1	2	3	4	5	6	7	8	9	10

13) When using the joystick to enter flight commands to the MAV, maintaining awareness of individual mission objectives was

easy									difficult
1	2	3	4	5	6	7	8	9	10

14) When using the LEFT thumb stick (forward, back, left & right movements) to move the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

15) Using the RIGHT thumb stick (up, down & rotation) to move the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

16) When using the joystick to stop the motion of the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

17) When using the joystick to switch between camera views (highlighting the camera icon located on the task bar), the display reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

For Joystick condition skip to question 18 on next page.

FOR MOUSE CONDITION ONLY Substitute the following for Questions 11 - 17:

11) When controlling the MAV in flight using the mouse, the device was

easy to use									*difficult to use*
1	2	3	4	5	6	7	8	9	10

12) As I progressed through the missions using the mouse, my hand and/or wrist became fatigued

Never									*Always*
1	2	3	4	5	6	7	8	9	10

13) When using the mouse to enter flight commands to the MAV, maintaining awareness of individual mission objectives was

Easy									*Difficult*
1	2	3	4	5	6	7	8	9	10

14) Using the LEFT/RIGHT buttons to move MAV while in manual control, the air vehicle reacted as I expected.

Always									*Never*
1	2	3	4	5	6	7	8	9	10

15) Using the ROTATE buttons to move the MAV while in manual control, the air vehicle reacted as I expected.

Always									*Never*
1	2	3	4	5	6	7	8	9	10

16) Using the Stop (X) button to stop the motion of the MAV while in manual control, the air vehicle reacted as I expected.

Always									*Never*
1	2	3	4	5	6	7	8	9	10

17) When using the icon to switch between camera views (located on the task bar), the display reacted as I expected.

Always									*Never*
1	2	3	4	5	6	7	8	9	10

18) While using the camera to take snapshots of targets, centering the target so it was aligned with the ( ) overlay was

easy									difficult
1	2	3	4	5	6	7	8	9	10

19) When piloting the MAV in manual control, determining the current heading of the MAV from the 360-degree directional heading tape was

clear									confusing
1	2	3	4	5	6	7	8	9	10

20) It was clear when the air vehicle had landed

always									never
1	2	3	4	5	6	7	8	9	10

21) The system provided adequate feedback when I issued a command to the MAV.

always									never
1	2	3	4	5	6	7	8	9	10

22) The OCU interface keeps you informed about what it is happening

always									never
1	2	3	4	5	6	7	8	9	10

23) Learning to operate the system was

easy									difficult
1	2	3	4	5	6	7	8	9	10

24) Remembering names and use of commands was

easy									difficult
1	2	3	4	5	6	7	8	9	10

25) Tasks could be performed in a straightforward manner

always									never
1	2	3	4	5	6	7	8	9	10

26) Training materials were

clear									confusing
1	2	3	4	5	6	7	8	9	10

27) After this training, I am ready use this system to fly a real air vehicle

very confident									not at all confident
1	2	3	4	5	6	7	8	9	10

28) The flight speed of the MAV was

fast enough									too slow
1	2	3	4	5	6	7	8	9	10

29) The responsiveness of the system to my input was

Fast enough									Too slow
1	2	3	4	5	6	7	8	9	10

30) System reliability was

reliable									unreliable
1	2	3	4	5	6	7	8	9	10

31) Correcting your mistakes was

easy									difficult
1	2	3	4	5	6	7	8	9	10

32) Both experienced and inexperienced users' needs were taken into consideration

always									never
1	2	3	4	5	6	7	8	9	10